The Power of Substitution: The Great German Gas Debate in Retrospect

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ABSTRACT The Russian attack on Ukraine in February 2022 laid bare Germany's dependence on Russian energy imports and ignited a heated debate on the costs of a cutoff from Russian gas. While one side predicted economic collapse, the other side (ours) predicted "substantial but manageable" economic costs due to households and firms adapting to the shock. Using the empirical evidence now at hand, this paper studies the adjustment of the German economy after Russia weaponized gas exports by cutting Germany off from gas supplies in the summer of 2022. We document two key margins of adjustment. First, Germany was able to replace substantial amounts of Russian gas with imports from third countries, underscoring the insurance provided by openness to international trade. Second, the German economy reduced gas consumption by about 20 percent, driven mostly by industry (26 percent) and households (17 percent). The economic costs of demand reduction were manageable with the economy as a whole only experiencing a mild one-quarter contraction in the winter of 2022–2023 and then stagnating. Overall industrial production decoupled from production in energy-intensive sectors (which did see large drops) and declined only slightly. We draw a number of key lessons from this important case study about the insurance offered by access to global markets

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and the power of substitution, specifically that supply shocks have dramatically smaller costs when elasticities of substitution are very low (but nonzero) compared to a truly zero elasticity.

> "Do we knowingly want to destroy our entire economy?"
>
> —BASF CEO Martin Brudermüller,
> *Frankfurter Allgemeine Zeitung*, March 31, 2022[1]

On March 7, 2022, less than two weeks after the Russian invasion of Ukraine, we published, jointly with a group of coauthors, a paper that addressed a seemingly simple question: what if the German economy was cut off from Russian gas? At that point, Germany imported about 55 percent of its gas consumption from Russia and relied on Russia for close to one-third of its total energy consumption (Bachmann and others 2022b). The "what if" question was intentionally framed in a way that allowed the cutoff to be the result of a German embargo or the result of an end to gas supplies initiated by Russia. The aim of the paper was to provide a compass for policymakers facing momentous decisions. How would the German economy cope with a sudden stop of energy imports from Russia? Would the likely result be a severe recession like during the global financial crisis or perhaps even a massive collapse in output and spiking unemployment comparable in its severity to the Great Depression of the 1930s? Or should we expect the economic costs to be more muted, that is, a more ordinary recession of the kind that the German economy had dealt with in the past and was well equipped to deal with in terms of the available policy space to cushion its impact?

Our answer at the time, based on key statistics about the German economy, relevant empirical estimates, and applied macroeconomic theory, was that an immediate emancipation from Russian energy was feasible and would entail substantial but manageable economic cost for the German economy. Our analysis foresaw an output cost in the first year following such a cutoff in the range of 1 to 3 percent relative to a no-cutoff baseline scenario, in line with previous recessionary episodes that the country had successfully dealt with. This prediction was highly controversial at the

1. The German company BASF is the largest chemical producer in the world and was heavily reliant on Russian gas until Russia cut off gas supplies to Germany in the summer of 2022. In the same interview, Brudermüller also warned that a cutoff from Russian gas "could bring the German economy into its worst crisis since the end of World War II and destroy our prosperity" (Brankovic and Theurer 2022).

time and triggered an intense public debate that culminated in the German chancellor warning of the "irresponsible" use of mathematical models for policymaking on a prime-time talk show.[2] Fearing catastrophic economic consequences of an end to Russian gas, the German government decided to keep importing rather than sanctioning it. Moreover, partly because of the fear of Russia retaliating by cutting off gas supplies, the German government was widely perceived to have taken a softer stance in offering support to the Ukrainian government and imposing other sanctions on Russia.

The Russian gas soon stopped flowing nevertheless. But it was Russia, not Germany or the European Union, that made the decision. Starting in June 2022, Russia drastically reduced gas supplies to Europe, in particular through the important Nord Stream 1 pipeline running directly from Russia to Germany in the Baltic Sea. Russia halted the Nord Stream 1 flows completely at the end of August 2022, and the pipeline was destroyed by underwater explosions four weeks later, resulting in a complete severance of Russian supplies to Germany.[3] One and a half years after the initial debate and a year after the final cutoff, this paper takes stock of what we have learned since then. We briefly review the original argument and the controversy it caused, but mainly focus on how the German economy coped with the actual severance of Russian gas supplies.

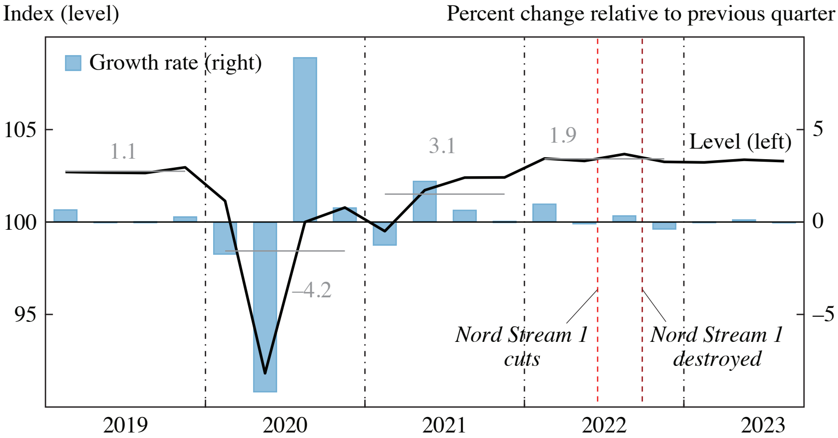
Prima facie, the evidence seems to support the original argument of the "what if" paper (Bachmann and others 2022b). Germany was partially cut off from Russian gas in June 2022 and completely in August 2022 but did not go into a deep depression. As shown in figure 1, Germany's gross domestic product (GDP) expanded by close to 2 percent for the entire year 2022 despite a circa 20 percent drop in gas consumption. In the fourth quarter of 2022, during the peak of the winter's heating season, the GDP contracted by 0.4 percent and stagnated thereafter, with growth in each of the first three quarters of 2023 close to 0 percent.[4] This outcome must be

2. *Anne Will* show with Chancellor Olaf Scholz on March 27, 2022; see https://benjaminmoll.com/Scholz/ for a transcript of excerpts with an English translation of Chancellor Scholz's comments. Key excerpt: "But they get it wrong! And it's honestly irresponsible to calculate around with some mathematical models that then don't really work."

3. BBC News, "Nord Stream 1: How Russia Is Cutting Gas Supplies to Europe," September 29, 2022, https://www.bbc.com/news/world-europe-60131520.

4. Of course, the observed evolution of German GDP is not directly comparable to a counterfactual prediction like ours that was relative to a no-cutoff baseline scenario holding other factors constant. The numbers for observed GDP have also been subject to repeated revisions. The data as of October 30, 2023 indicate that Germany experienced a technical recession (defined as two consecutive quarters of negative GDP growth) in the winter of 2022–2023 by the narrowest of margins, with GDP contracting by 0.4 percent and then 0.03 percent in the fourth quarter of 2022 and the first quarter of 2023.

Figure 1. Real GDP in Germany



Source: Destatis.

Note: The GDP data, seasonally and calendar adjusted, are from table 81000-0002 of the German National Accounts, available through Destatis at https://www-genesis.destatis.de/. The GDP level (left y-axis) is normalized to 100 in 2020:Q3, the quarter after the 2020 pandemic recession. Russia cut gas deliveries through the Nord Stream 1 pipeline substantially starting in mid-June 2022 (first to 40 percent, then 20 percent, "Nord Stream 1 cuts") and halted flows completely on August 31, 2022. The pipeline was destroyed on September 26, 2022 ("Nord Stream 1 destroyed").

compared to the estimates in studies financed by trade unions and business associations that foresaw output losses between 6 percent and 12 percent, with the most apocalyptic estimates due to Krebs (2022) and Prognos (2022), both of which predicted an output collapse of 12 percent, as well as Michael Hüther, who warned of "two and a half or three million additional unemployed" (IW 2022).[5] Overall, while the German economy is stagnating and faces substantial long-run headwinds, the direct economic costs

5. See Behringer and others (2022), Krebs (2022), and Prognos (2022). Even though counterfactual GDP predictions and the GDP time series are not directly comparable, it is clear that these dramatic counterfactual estimates between 6 percent and 12 percent have not come true. For example, given that GDP growth was close to zero over the 2022–2023 period, in order to believe a 12 percent GDP drop relative to a no-cutoff baseline scenario, one would have to believe that GDP would have grown at around 12 percent in the absence of a gas import stop, which is clearly absurd. For context, the Institut für Makroökonomie und Konjunkturforschung (IMK), which produced the report by Behringer and others (2022) is a union-financed think tank; the Krebs (2022) study was paid for by the German trade union federation, Deutscher Gewerkschaftsbund (DGB); and the Prognos study was paid for by a business association. See Bachmann and others (2022a) and Moll (2022) for a

of the end of Russian energy imports proved moderate and manageable, in line with the results of the original “what if” study.

In this paper, we have four main ambitions. First, we lay out the basic theoretical considerations regarding the economy’s ability to adapt. One important and nonobvious point is that even very low elasticities of substitution are a powerful force for reducing the impact of a large input supply shock like the gas cutoff. While a Leontief production structure (i.e., the case in which elasticities are truly zero) implies drastic economic costs, specifically that production falls one-for-one with gas, even moderate substitutability mutes these costs considerably. The simplest illustration of this result uses a calibrated aggregate production function with an elasticity of substitution between gas and other inputs: in the Leontief case $\sigma = 0$, a 20 percent drop in gas supplies implies a 20 percent drop in production; however, when $\sigma = 0.05$, the corresponding output losses are only 2.7 percent, that is, going from $\sigma = 0$ to $\sigma = 0.05$ reduces the output loss by a factor of almost ten. The underlying logic is considerably more general, however, and extends to richer multi-sector models of supply chains like the model in Baqaee and Farhi (2024) used by Bachmann and others (2022b) to explore the importance of cascading effects in production (see section II). Intuitively, because the share of gas in production is small, even a small amount of substitutability is sufficient to overcome the gas input’s bottleneck property. In the more complicated models, additionally, international trade plays an important role, specifically substitution of gas-intensive products via imports.

Second, we show how the German economy adapted to the end of Russian gas supplies. We track the consumption response of households and industries on the demand side and discuss the additional supply that replaced Russian gas. On the supply side, Germany was able to replace substantial amounts of Russian gas with imports from third countries, often taking advantage of the integrated European gas market, for example by importing US liquified natural gas (LNG) via LNG terminals in the Netherlands. On the demand side, the German economy reduced overall gas consumption by about 20 percent in the period July 2022 to March 2023

summary of studies conducted by other entities. For comparison, the German labor force was around 44 million people in 2022, so 2.5–3 million additional unemployed would have corresponded to an increase in the unemployment rate of more than 5 percent (data from World Bank, “Labor Force, Total – Germany,” https://data.worldbank.org/indicator/SL.TLF.TOTL.IN?locations=DE). Michael Hüther is the head of industry-financed think tank Institut der Deutschen Wirtschaft (IW) Köln.

relative to previous years.[6] The largest contribution came from industry, which reduced its gas consumption by a striking 26 percent, whereas household gas consumption fell by a smaller but still impressive 17 percent. The online appendix complements these statistics by describing thirty-six concrete cases of substitution and adaptation by German firms and households.

We pay particular attention to the adjustment of the industrial sector to the gas cutoff. Much of the German debate in February and March 2022 centered around "cascading effects" in production, the idea that a cutoff from Russian gas would not only affect energy-intensive upstream sectors but also subsequently take down and "destroy" the entire industrial sector and economy with it—the quote by the BASF chemicals executive at the beginning of our paper is a good example of this line of argument. We therefore ask what sectors were most affected by the gas cutoff, and whether and to what extent it resulted in such cascading effects. While production in energy-intensive sectors like chemicals and glass production did see substantial cuts of up to 20 percent, we find no evidence of substantive cascading effects. To the contrary, we find that overall industrial production displayed a substantial decoupling from production in these energy-intensive sectors and was hardly affected. In an open economy with substitution possibilities, sharp declines in output in some upstream sectors do not necessarily lead to large contractions in downstream industries. At each point in the production network, substitution possibilities exist.

Third, we ask if Germany could have also withstood an earlier cutoff from Russian gas, as early as the end of March 2022, as advocated by some and hotly contested by others. A prominent line of thinking among the skeptics is that the additional five months from April to August, during which Germany continued to import and stockpile Russian gas, was decisive as it allowed the country to purchase enough Russian gas to increase storage capacity sufficiently to get through the following winter. By contrast, an immediate severance from Russian energy at the end of March 2022 would have resulted in storages running out in the middle of the winter as well as shortages and rationing, and an ensuing economic catastrophe.

We revisit this argument and show that Germany exited the 2022–2023 heating period with gas reserves that exceeded imports from Russia from April to August 2022. In other words, even in the scenario of a Russian supply cutoff at the end of March 2022, Germany would have had enough

6. The 20 percent overall demand reduction that we document is somewhat below other estimates in the literature. For example, Ruhnau and others (2023) find that gas consumption during the second half of 2022 was 23 percent below the temperature-adjusted baseline.

gas to make it through the following winter (assuming identical consumption). While actual observed gas storage levels were around 65 percent at the end of the 2022–2023 heating period, they would have still been around 25 percent even in the counterfactual scenario of an immediate cutoff. Moreover, as the March cutoff would have coincided with the end of the 2021–2022 heating period, the combination of gas imports from other countries and preexisting storage would have been sufficient to satisfy both industrial and household gas demand at any point in time. There would never have been a gas shortage at any point throughout the year, and German gas storage levels would have instead always exceeded a safety margin of around 25 percent. In other words, on the basis of this simple calculation, Germany would have been able to cope with an earlier embargo on Russian gas imports. The country's leaders likely overestimated the geoeconomic dependency on Russia and arguably opted for a more cautious policy toward Russia than was necessary.

Last, we briefly discuss the political economy of policy consulting and the role domestic lobbies have played in the process. We also look back critically and argue that Germany could have done more to help Ukraine at an earlier stage, and that there are important lessons for related cases in the future, such as China and Taiwan. Market economies have a tremendous ability to adapt, which we should not underestimate again.

The structure of this paper is as follows. We start with a short exposition of Germany's dependence on Russian gas before the Russian invasion of Ukraine and the events leading up to the eventual cutoff. Section II recaps the argument of the "what if" paper, specifically that substitution would be a powerful force toward lowering the costs of a gas cutoff. Section III discusses the adjustment that has taken place over the past year and benchmarks the development to the prediction of the model. Section IV asks whether an immediate disruption in April 2022 would have had much more severe consequences. Section V considers the role of "luck," specifically whether the 2022–2023 winter was particularly mild, as well as various other factors in global energy markets. Section VI discusses the main lessons from the debate for policy consulting and similar future episodes. Section VII concludes.

I. Background: Germany's Dependence on Russian Gas and the 2022 Gas Cutoff

Long ignored by German politicians, Germany's dependence on gas imports from Russia was exposed dramatically after the Russian aggression. How Germany became so dependent on Russian gas even though the Russian government had weaponized its gas exports in the past (in particular against Eastern European countries like Ukraine), is a fascinating question for political scientists. A recent book by Bingener and Wehner (2023) provides an excellent analysis of the mix of political economy problems, industrial lobbying, naïveté, and outright corruption that led to this dependence. After Russia's attack on Ukraine, the question of economic dependence became one of acute geoeconomic relevance: to what extent were Germany's options to support Ukraine and take a tough stance on Russia compromised by the country's dependence on Russian gas?

Yet the European gas crisis started well before the Russian attack on Ukraine. Already in the summer of 2021, gas storages in Europe were not being refilled at the usual pace. Specifically, Russia's gas monopolist Gazprom controlled a number of storage facilities at the time, including Germany's largest one (Rehden), and purposely kept them almost empty. Russia gradually reduced gas supplies, withholding almost 20 percent of the usual pipeline flows it delivered to Europe in previous years. This led to sharply increasing gas prices from below €20 per MWh at the beginning of 2021 to a first peak of close to €100 per MWh in October, and a second peak of close to €150 per MWh in December 2021.[7] This gradual withholding of volumes by Russia went largely unnoticed by the media and did not enter into the public debate, likely in part due to the difficult access to gas flow data. Some commentators and so-called experts circulated various theories on technical, commercial, and legal reasons for the reduced flows, thereby preventing a sense of urgency among the policymakers and the public.

The start of the war had little direct impact on prices and volumes. However, when it became clear that Kyiv would not be taken in a few weeks and a coalition of Western countries formed that supported Ukraine and put substantial sanctions on Russia, Russia soon started further weaponizing its gas exports. To begin, the Russian president Vladimir Putin decreed on March 31, 2022,[8] that Gazprom would only receive payments for gas in Russian rubles. Even though this contradicted agreed contract terms and risked undermining financial sanctions, European policymakers were reluctant to offer clear guidance to their companies on this issue, likely due to the perceived importance of Russian gas imports for the functioning of Europe's economy. Subsequently, Gazprom stopped gas deliveries to Poland and Bulgaria for refusing to pay in rubles. Moreover, flows

7. Investing.com, "Dutch TTF Natural Gas Futures Interactive Chart," https://www.investing.com/commodities/dutch-ttf-gas-c1-futures-advanced-chart.

8. Reuters, "Putin's Decree on Russian Gas Purchases in Roubles," March 31, 2022, https://www.reuters.com/article/idUSL5N2VY5U7/.

through the Yamal pipeline (that passes Poland toward Germany) were also stopped by Russia based on claims of Polish sanctions against the pipeline company. In June 2022, Russia unilaterally limited gas flows through the Nord Stream 1 pipeline to 40 percent, then reduced them further to around 20 percent and eventually halted flows completely on August 31, 2022.[9]

These politically tense months between February and September 2022 were characterized by a Russian strategy to divide European unity, for example by selectively cutting gas supplies to specific countries while at the same time offering to Germany to open the newly built Nord Stream 2 pipeline so as to avoid the much-feared gas crisis.

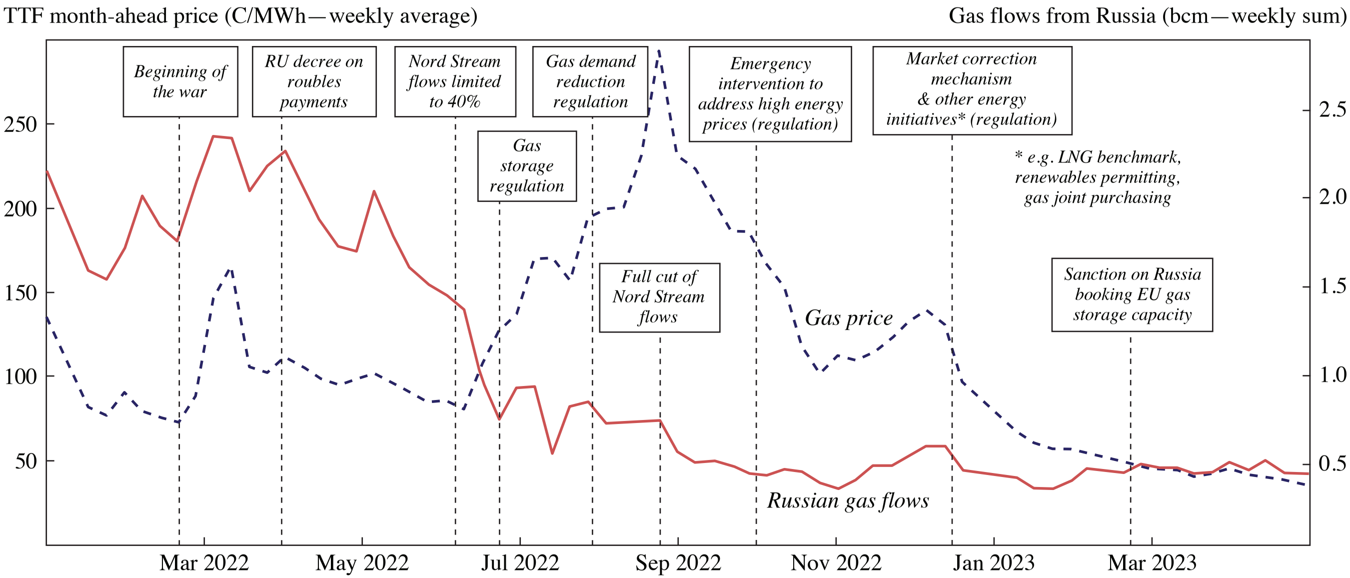
Finally, on September 26, 2022,[10] the two branches of Nord Stream 1 and one of the two branches of Nord Stream 2 were destroyed by underwater explosions in the Baltic Sea (with the actors unknown at the time of writing). The destruction of the Nord Stream pipelines ended this phase of uncertainty by substantially cutting Russian gas flows to Europe (routes via Turkey and Ukraine remained operational), in particular ending direct pipeline flows from Russia to Germany for good. While Germany imported more than half of its gas from Russia in 2021 (table 1), and this was expected to further increase with the planned opening of Nord Stream 2 at the beginning of 2022, the share of Russian gas fell to 0 percent by September 2022 (online appendix figure C.1). Figure 2 is reproduced from Gil Tertre (2023) and shows the key events over time.

The starting point of our "what if" paper was a summary of Germany's dependence on Russian energy at the beginning of the war in Ukraine (table 1). One energy input stood out: natural gas. In particular, data from 2021 showed that Germany imported more than half (55 percent) of its gas from Russia. Furthermore, Germany was much more dependent on natural gas than many other countries, with natural gas accounting for nearly a third of the overall energy mix.

9. Nina Chestney, "Russian Gas Flows to Europe Fall, Hindering Bid to Refill Stores," Reuters, June 16, 2022, https://www.reuters.com/markets/europe/russian-gas-flows-europe-fall-further-amid-diplomatic-tussle-2022-06-16/; Reuters, "Russia's Gazprom Tightens Squeeze on Gas Flow to Europe," July 26, 2022, https://www.reuters.com/business/energy/kremlin-nord-stream-1-turbine-be-installed-volumes-will-adjust-2022-07-25/; and Reuters, "Gazprom to Shut Down Nord Stream 1 Pipeline for 72 Hours," August 30, 2022, https://www.reuters.com/business/energy/nord-stream-1-nominations-fall-zero-aug-31-0200-cet-2022-08-30/.

10. Niha Masih, "Who Blew up the Nord Stream Pipelines? What We Know One Year Later," *Washington Post,* September 25, 2023, https://www.washingtonpost.com/world/2023/09/25/nord-stream-pipeline-explosion-update-russia-ukraine/.

Figure 2. Russian Weaponization of Gas Supplies and Gas Prices



Source: Reproduced from Gil Tertre (2023), copyright European Union.

Table 1. German Primary Energy Usage 2021

	Oil	*Natural gas*	*Coal*	*Nuclear*	*Renewables*	*Others*	*Total*
TWh	1,077	905	606	209	545	45	3,387
Percent	31.8	26.7	17.9	6.2	16.1	1.3	100
Percent (Russia)	34	55[a]	26	0	0	0	30

Source: Reproduced from Bachmann and others (2022b) with permission, copyright ECONtribute.
a. In 2020; already lower in 2021 and 2022.

In contrast to the other energy imports from Russia (oil and coal), it was also clear that Russian gas would be considerably harder to substitute with imports from third countries (like Norway or the Netherlands). This is due to German gas imports having been pipeline-bound, in particular from Russia via the Nord Stream and Yamal pipelines, and Germany at the time not having even a single terminal for importing LNG. The combination of Germany's large dependence on Russian gas and the difficulty in substituting this Russian gas with imports from other countries meant that we focused our analysis on the economic costs of a cutoff from Russian gas.

II. The Core Argument: The Power of Substitution

The core theoretical argument of the "what if" paper was that German firms and households would adapt to a cutoff of Russian gas supplies in ways that would ultimately reduce the economic impact. Producers would switch to other fuels or fuel suppliers and import products with high energy content, while households would cut their gas demand by turning down their thermostats. Importantly, elasticities of substitution that are very low, but nonzero, translate into much smaller economic losses than in the case of literally zero substitutability (i.e., Leontief production). Substitution along the supply chain and across producers would mean that macro elasticities are larger than micro elasticities. Cascading effects along the supply chain would be muted as opposed to "destroying" the economy's entire industrial sector.

Using the approaches we outline below, we argued that even in the case of a cold turkey import stop of Russian gas in March or April 2022, the economic costs would be substantial but manageable. Our analysis foresaw GDP and gross national expenditure (GNE) losses in the first year after such a cutoff in the range of 1–3 percent relative to a no-cutoff baseline scenario.

II.A. An Aggregate Production Function

To illustrate the power of substitution in a transparent fashion, we start by considering an extremely simple and purposely stylized setup. We assume that Germany produces output Y using natural gas G (which it imports from Russia) as well as other inputs X (like labor and capital), according to a constant elasticity of substitution (CES) aggregate production function

$$Y = \left(\alpha^{\frac{1}{\sigma}} G^{\frac{\sigma-1}{\sigma}} + \left(1-\alpha\right)^{\frac{1}{\sigma}} X^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}, \tag{1}$$

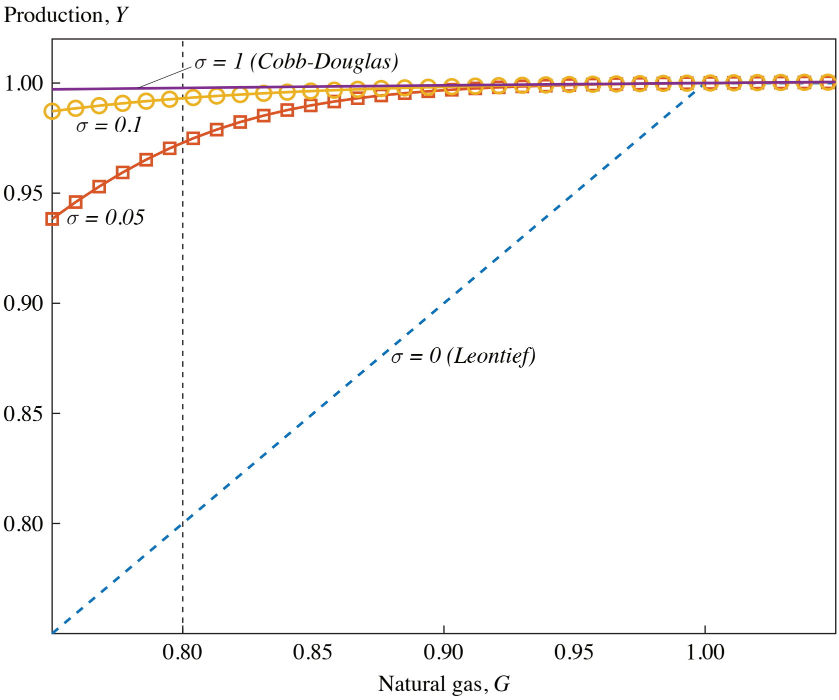
where $\alpha > 0$ parameterizes the importance of gas in production and $\sigma \in [0, \infty)$ is the elasticity of substitution between gas and other inputs. The goal is to assess the effect of a drop in gas supply G on production Y and how this depends on the features of the aggregate production function. The setup is, of course, extremely simplistic in that it only features two factors of production, no input-output linkages, and so on. However, as we discuss below, such an analysis can be a good approximation even in a much richer environment like the multi-sector model of Baqaee and Farhi (2024) used further below.

The following special cases show that, depending on the value of σ, the macroeconomic effects of a drop in gas supplies G are extremely different. The examples are complemented by figure 3, which plots production Y as a function of natural gas G for different values of the elasticity σ for a calibration described in Bachmann and others (2022b) in which the share parameter α equals 1 percent.[11]

A particularly useful special case is that of Leontief production, that is, exactly zero substitutability $\sigma = 0$, in which case equation (1) becomes $Y = \min\{G/\alpha, X/(1-\alpha)\}$. Starting from an initial optimum, a reduction in G implies that $Y = G/\alpha$ and hence $\Delta \log Y = \Delta \log G$. Therefore, if the elasticity of substitution is exactly zero, production Y drops one for one with gas supply G. This is illustrated by the dashed line in figure 3, which plots production Y as a function of G for the Leontief case. For example, a drop in gas supply of $\Delta \log G = -20\%$ implies a drop in production of $\Delta \log Y = -20\%$. Intuitively, the Leontief assumption means that, despite its small input

11. Bachmann and others (2022b) document that the share of natural gas consumption in German GNE is roughly 1 percent. This is also the share of gas imports in GNE because there is hardly any domestic production of natural gas.

Figure 3. Output Losses Following a Fall in Gas Supply for Different Elasticities of Substitution



Source: Authors' calculations.

share, gas is an extreme bottleneck in production: when energy supply falls by 20 percent, the same fraction (that is, 20 percent) of the other factors of production X lose all their value (their marginal product drops to zero), and hence production Y falls by 20 percent. Note that this output loss is completely independent of the input share α: with Leontief production, even a tiny input becomes an extreme bottleneck and takes down the economy one for one. That zero substitutability predicts production falling one for one with gas is much more general and is also true in multi-sector models with complex supply chains.

On the other extreme, the special case of Cobb-Douglas production with an unrealistically high elasticity of substitution of $\sigma = 1$ implies very small output losses. When $Y = G^{\alpha} X^{1-\alpha}$ we have $\Delta \log Y = \alpha \times \Delta \log G$ so that a 20 percent gas drop implies an output loss of only 0.2 percent ($1\% \times (-20\%) = -0.2\%$).

The most important conclusion, however, concerns intermediate cases with low but nonzero substitutability like $\sigma = 0.05$. The solid line with square markers in figure 3 plots the output losses for this case. It shows that the case with moderate but nonzero substitutability $\sigma = 0.05$ is very different from the Leontief case with literally zero substitutability $\sigma = 0$. For example, a 20 percent gas supply drop leads to an output loss of 2.7 percent rather than 20 percent, that is, going from $\sigma = 0$ to $\sigma = 0.05$ reduces the output loss by almost a factor of ten (at the same time, there is still substantial amplification relative to the 0.2 percent output loss in the Cobb-Douglas case $\sigma = 1$, again by roughly a factor of ten). Intuitively, because the input share $\alpha = 1\%$ is small, even a small amount of substitutability is sufficient to overcome the gas input's bottleneck property. In summary, while a Leontief production function predicts that production falls one for one with gas, even moderate substitutability implies much smaller losses.

For completeness and with an eye to other applications, we note that the value of the share parameter can also make a big difference. For example, suppose that $\alpha = 2\%$ rather than 1%. Then, in the Leontief case $\sigma = 0$, the output loss from a 20 percent gas supply drop is still 20 percent, that is, it is unaffected by the share parameter α. However, when $\sigma = 0.05$, $\alpha = 2\%$ implies an output loss of 4.5 percent rather than 2.7 percent. This point is particularly relevant in the context of other scenarios, for example, oil shocks (see section III.F) or China-Taiwan tensions.

Finally, it is worth noting that Bachmann and others (2022b) evaluated the effects of a gas cutoff not just on GDP but also on Gross National Expenditure (GNE). GNE, also known as "domestic absorption," is the economy's total expenditure defined as the sum of household expenditure, government expenditure, and investment, that is, $GNE = C + I + G$ in the GDP accounting identity $GDP = C + I + G + X - M$. GNE (rather than GDP) is the welfare-relevant quantity in many macroeconomic and trade models, including the Baqaee-Farhi model. One reason for focusing on GNE rather than GDP is that GDP may not pick up the terms of trade effect through which German consumers become poorer when the price of natural gas (an imported good) rises (Obstfeld and Rogoff 1995; Mendoza 1995).[12] Sinn (2022) misguidedly criticized the analysis of Bachmann and

12. Theoretically the effect is easiest to see in a small open endowment economy with an exogenously given relative price of exports to imports p (which is the country's terms of trade). Real GDP is given by the endowment and therefore not affected by fluctuations in the terms of trade p. However, consumption and welfare decline when the terms of trade p decline, an effect not picked up by real GDP.

others (2022b) for missing this effect even though GNE is not subject to this criticism.[13]

II.B. Macro Elasticities Are Larger than Micro Elasticities

The question under consideration in the great gas debate was the potential impact of a cutoff from Russian gas on the German macroeconomy. However, many arguments focused on very micro physical production processes, with industry leaders claiming that substitutability of Russian gas was very close to zero. Bachmann and others (2022b) argued that this "micro" or "engineering view" of substitution is too narrow and misses important mechanisms through which the macroeconomy would adapt to an import stop.

Macro elasticities of substitution are larger than the corresponding micro elasticities. That is, even if substitution is completely impossible at the very micro level, this does not necessarily mean that there is no substitution in the aggregate economy. Technically, single production processes may be very close to displaying a zero elasticity of substitution (Leontief), but they may still aggregate up to an economy with a positive and potentially much higher elasticity of substitution. The observation that zero or low substitution at the micro level does not necessarily imply low substitution at the macro level, goes back to a classic paper by Houthakker (1955) who showed that an economy in which individual firms that have Leontief production technologies (i.e., individual elasticities of substitution of zero) can aggregate up to a Cobb-Douglas aggregate production function (i.e., an aggregate elasticity of substitution of one). More generally, it is a classic result in macroeconomic theory that the elasticity of substitution increases with the level of aggregation (Jones 2005; Oberfield and Raval 2021).

The apparent lack of substitutability is thus a classic "micro-to-macro fallacy" (of which there are a number in economics). It also provides a straightforward explanation for why many industry representatives seem

13. Sinn writes: "Many have called for an embargo on European imports of Russian gas, arguing that this would [come] at minimal cost to Europe in terms of lost GDP [including a hyperlink to Bachmann and others (2022b)]. A new study exposes this argument for the fantasy that it is. . . . Due to the terms-of-trade effect, the welfare of consumers of gas and gas-intensive goods would decline as the price of these now-imported items increases [an effect missed by considering real GDP]" (Sinn 2022, par. 2–4). That $GNE = C + I + G$ is not subject to this criticism is easiest to see in models without investment or a government in which it just equals welfare-relevant consumption C. A possible reason for Sinn's misguided criticism is that he did not read Bachmann and others (2022b) past the executive summary, thus missing the analysis in terms of GNE.

to believe that the world is one of little substitution (a “Leontief world”): they are actually right at the micro-micro level, and this “engineering viewpoint” biases them to also view the macroeconomy in this fashion. (Of course, the alternative explanation for the apparent belief is simply industrial lobbying, a point we return to later.)

II.C. The Importance of Time: The Le Chatelier Principle and Seasonality of Gas Demand

Another important observation about elasticities of substitution is that they increase with the time horizon over which the substitution ought to take place. Switching a glass melting furnace from gas to fuel oil from one day to the next is probably impossible, but given enough time, such a switch may well be feasible.[14] The idea that elasticities increase with time has become known as the Le Chatelier principle (Samuelson 1947; Milgrom and Roberts 1996).[15] It is also well known that gas demand is strongly seasonal, with demand being about three times higher in winter than in summer, primarily due to households using gas for heating.[16]

The Le Chatelier principle in combination with the seasonality of gas demand was one important reason why Bachmann and others (2022b) argued that an immediate, cold turkey import stop in April 2022 would not entail much larger economic costs than an import stop in the summer or early fall. Because a cutoff at the beginning of April would have coincided with the end of the previous heating period and a drop-off in household demand, gas supplies would have been sufficient at any point in time to satisfy both industrial and household gas demand and to avoid shortages.

In particular, also in the case of an April 2022 import stop, industry would have had time until the following winter to conserve and substitute gas. While a cold turkey import stop would have resulted in less gas imports from Russia and thus a larger required demand reduction, it would have arguably also sent the signal to industry to start substituting and adapting at full speed already from April rather than only later in the summer and thus longer adjustment times until the next winter (i.e., larger elasticities of substitution by the Le Chatelier principle). See section IV for a detailed analysis of the importance of gas imports from Russia from April to August 2022.

14. Switching glass melting furnaces from gas to fuel oil is not a hypothetical example but actually happened; see example 13 in the collection of thirty-six substitution examples in online appendix E.

15. Atkeson and Kehoe (1999) build models of energy use that rationalize the Le Chatelier principle.

16. See, for example, figure 2 in Bachmann and others (2022a).

II.D. Modeling Supply Chains and International Trade: Cascading Effects and Substitution via Imports

Much of the German debate in February and March 2022 centered around cascading effects in production, the idea that a cutoff from Russian gas would not only affect energy-intensive upstream sectors but also subsequently take down the entire supply chain and industrial sector with it. For example, a drop in gas supply would lead to a drop in glass production (a very gas-intensive product), which would lead to a drop in the production of bottles, then a drop in the production of medicine, which would affect the ability to provide hospital care, and so on. Theoretically, if production were Leontief and elasticities of substitution were zero everywhere along the supply chain, then a 20 percent drop in gas supplies would lead to a 20 percent drop in glass production, the production of bottles, and so on, and ultimately to a 20 percent drop in economy-wide industrial production.

To take the possibility of knock-on effects along the supply chain seriously, Bachmann and others (2022b) modeled such supply chains using the Baqaee and Farhi (2024) model. The Baqaee-Farhi model is a multi-sector model with rich input-output linkages and in which energy is a critical input in production. The model is designed to address questions in which supply chains or production networks play a key role, specifically how a shock to an upstream product (e.g., an energy input) propagates downstream along the supply chain, that is, the cascading effects discussed above. The model features forty countries as well as a composite country representing the rest of the world, and thirty sectors with interlinkages that are disciplined with empirical input-output matrices from the World Input-Output Database (Timmer and others 2015). Each entry of the World Input-Output matrix represents a country-sector pair; for example, we use data on the expenditure of the German "Chemicals and Chemical Products" sector on "Electricity, Gas and Water Supply" and how much of this expenditure goes to different countries, say how much goes to Germany itself and how much to Russia. The model features a nested CES structure.

The idea that input-output linkages can serve as a propagation mechanism for such shocks is well established in the literature. See Carvalho and Tahbaz-Salehi (2019) for a review of this literature and Carvalho and others (2021) for a prominent example studying the propagation of the 2011 Japan earthquake that destroyed the Fukushima nuclear plant.

As just mentioned, the Baqaee-Farhi model features not only multiple sectors but also multiple countries and thus international trade. The analysis using this type of model points to one margin of substitution that turned out to be important in practice: substitution of gas-intensive products via imports. Intuitively, it is not necessary for German producers to substitute gas itself; instead, they can substitute the energy-intensive inputs they use in production, like ammonia, and they can do so via trade by importing those goods from another country. In this way, producers effectively import gas “embodied in” these inputs. Of course, this type of substitution via imports comes with some loss in production in the importing country (in this case, Germany). However, these losses may be small, and on the flip side, this substitution stops the notorious cascading effects.

Finally, it is worth noting that an empirically disciplined multi-sector model like the Baqaee-Farhi model reflects an important feature of modern advanced economies: manufacturing typically accounts for a moderate share of aggregate economic activity. This is true even for Germany, which is often viewed as an industrial powerhouse: German manufacturing accounts for only about 23 percent of total employment and 25 percent of value added.[17] This is a natural consequence of the structural transformation process during which manufacturing activity is replaced by the service sector. Put differently, some observers seem to be under the mistaken impression that the structure of the German economy is still that of earlier time periods like the 1970s, during which energy shocks had large negative effects.

II.E. A Useful Tool: The Baqaee-Farhi Sufficient Statistics Approach

In a number of papers, Baqaee and Farhi have popularized the use of second-order approximations to obtain analytical results in complex multi-sector models. Bachmann and others (2022b) use a variant of this approach to obtain a useful sufficient statistics formula that allows for quick back-of-the-envelope calculations.

The key idea of the approach is that the extent to which the upstream energy supply shock propagates through the production chain shows up in a sufficient statistic, namely, the change of the energy expenditure share in GNE induced by an import stop. Intuitively, when there are important bottlenecks along the supply chain and elasticities of substitution are low, energy prices skyrocket when energy supply falls, which implies that the energy expenditure share rises strongly.

It is relatively easy to verify that this insight is correct in the context of the simple aggregate production function (see online appendix A). Perhaps

17. See the appendix in Bachmann and others (2022b), which documents these numbers using Eurostat data.

surprisingly, Bachmann and others (2022b) show that it is also true in the much more complex multi-sector environment of Baqaee and Farhi (2024). Denoting gas imports by m_G and their price by p_G so that the gas expenditure share in GNE is given by $p_G m_G/GNE$, the effect of a shock to gas imports $\Delta \log m_G$ approximately equals

$$(2) \qquad \Delta \log GNE \approx \frac{p_G m_G}{GNE} \times \Delta \log m_G + \frac{1}{2} \times \Delta\left(\frac{p_G m_G}{GNE}\right) \times \Delta \log m_G.$$

The intuition for the second term is the one we already discussed: the change in the GNE share of gas imports $\Delta\left(\frac{p_G m_G}{GNE}\right)$ summarizes in a succinct fashion the substitutability implied by model choices about elasticities, the input-output structure, and so on.

The formula can be used for back-of-the-envelope calculations as follows. Consider, for example, a drop in gas imports by 30 percent so that $\Delta\log m_G = \log(0.7)$. The share of gas expenditure in GNE $\frac{p_G m_G}{GNE}$ equals about 1.2 percent. The second-order approximation also requires a number for the change in the expenditure share $\Delta\left(\frac{p_G m_G}{GNE}\right)$, a number that was not yet available in the data at the time of writing by Bachmann and others (2022b). In one of their calculations, they assumed that this share would quadruple to 4.8 percent. Using these numbers, the GNE losses are given by

$$(3) \qquad \Delta \log GNE \approx 1.2\% \times \log(0.7) + \frac{1}{2} \times (4.8\% - 1.2\%) \times \log(0.7)$$
$$\approx -1\%.$$

More generally, formula (2) can be used to bound the GNE loss from the shock: above a certain GNE loss number, the strong complementarities and cascading effects required to get there would imply an unreasonably large increase in the gas expenditure share, say, to 20 percent of GNE. It is worth noting that this logic applies not just to the Baqaee-Farhi model but also to a much wider class of general equilibrium models. Other analyses of import supply shocks should therefore always examine the model's predictions for changes in expenditure shares for their reasonableness.[18]

18. See also Berger and others (2022), who put the sufficient statistics approach based on formula (2) to good use.

II.F. Additional Arguments and Omissions from the Analysis

Less than two weeks after the release of Bachmann and others (2022b), we added a detailed appendix to the paper with a number of historical real-world examples that show how firms and households have found ways to substitute in adversity.[19] These include the Chinese rare earths embargo against Japan, the shutdown of the Druzhba pipeline, and various examples from World Wars I and II. There is one particularly relevant case study we were not aware of at the time, namely, the case of Chile getting cut off from Argentinean gas in 2007—see the illuminating discussion by Velasco and Tokman (2022) who were the Chilean finance and energy ministers at the time.

As the "what if" paper was clear to emphasize, our analysis used a real model with no further business cycle amplification and therefore omitted some of the channels through which a large energy supply shock may affect the economy. In particular, our model omitted standard Keynesian demand-side effects in the presence of nominal rigidities as well as amplification effects due to financial frictions. To be clear, our flexible-price model did include what many lay people would call demand-side effects, namely, that skyrocketing relative prices of energy erode purchasing power and consumer welfare. But it omitted the feedback from the drop in aggregate consumption to production and employment that is operational in Keynesian models with nominal rigidities and high marginal propensities to consume. To acknowledge such missing mechanisms, we added a "safety margin" to the results of their model simulations. In particular, our largest number in the "what if" paper was a GNE loss of 2.3 percent (see table 2 in the paper) which we rounded up to 3 percent when presenting our headline numbers (see the abstract). Perhaps reassuringly, work by our coauthor Christian Bayer (Bayer, Kriwoluzky, and Seyrich 2022), published a few weeks after the "what if" paper, as well as Pieroni (2023) used quantitative Heterogeneous Agent New Keynesian (HANK) models to take into account such Keynesian multiplier effects and largely confirmed our original results.[20]

19. See "Supplement to 'What If? . . .': Real-World Examples of Substitution and Substitution in the Macroeconomy" available at https://benjaminmoll.com/RussianGas_Substitution/.

20. Bayer, Kriwoluzky, and Seyrich (2022) and Pieroni (2023) modeled exactly the same gas supply shock as we did in Bachmann and others (2022b) but in HANK models. Bayer, Kriwoluzky, and Seyrich (2022) found that the upper bound of economic costs stayed below 3 percent of GDP, that is, below the "safety margin" we left ourselves, whereas Pieroni (2023) found that economic costs could reach up to 3.4 percent, that is, just outside our upper bound.

The main reason for these omissions was not that we deemed these effects unimportant. Instead, it was simply that we wrote the "what if" paper in a rush (ten days) and therefore, given time constraints, had to make choices about what channels to include in our analysis and what to leave out. We will revisit these points in section III.F, where we discuss which of these omissions were important with the benefit of hindsight and lessons for future analyses of similar scenarios.

III. How the Adjustment Happened: Adaptation and Substitution by German Industry and Households

A year after the final cutoff from Russian gas, we can take stock of what happened to the German economy. The most recent GDP numbers for the German economy were published at the end of July 2023. Prima facie, the evidence seems to support the original argument of the "what if" paper. Germany was partially cut off from Russian gas in June 2022 and completely cut off in August 2022, but the country did not go into a deep depression. Moreover, as shown in figure 1, German GDP not only did not collapse, but actually expanded by close to 2 percent for the entire year 2022. Even during the peak of the heating season of the 2022–2023 winter, Germany only experienced a mild one-quarter contraction, with GDP falling by 0.4 percent in the fourth quarter of 2022 and stagnating at close to 0 percent GDP growth during the first three quarters of 2023.[21]

Using the empirical evidence now at hand, this section documents how the adjustment actually played out. As we see now in greater detail in the rearview mirror, the economy showed a tremendous ability to adapt that was widely underestimated. Producers partly switched to other fuels and imported products with high gas content, while households adjusted their consumption patterns. Overall industrial production decoupled from production in energy-intensive sectors (which did see large drops) and was hardly affected. To lend some color to the statistics of this section, online appendix E collects thirty-six concrete cases of substitution and adaptation that show how German firms and households weaned themselves off Russian gas.

21. Other European countries also withstood Russia's weaponization of natural gas remarkably well. According to the most recent Eurostat GDP flash estimates for 2023:Q2 (Eurostat 2023), both the European Union and the euro area expanded in the first two quarters of 2023, and only a handful of individual member countries like Czechia and Estonia have experienced (shallow) recessions (defined as two consecutive quarters of negative GDP growth) since the beginning of 2022. The exception is Hungary, which has seen four consecutive quarters of negative GDP growth since 2022:Q3.

III.A. Germany's Changing Gas Balance: Large Adjustments on Both the Demand and Supply Sides

The end of Russian gas imports left a large gap in German gas supplies. How did the country adjust to close this gap? Was the adjustment primarily on the demand side, that is, lower gas consumption, or supply side, that is, increased imports from third countries? Figure 4 shows the change of the German gas balance for the period from July 2022 (when Russia cut gas supplies substantially; see section I) to March 2023 (the end of the heating period), compared to the preceding three years.

The cutoff from Russian gas reduced supply by 41 percent of total consumption in previous years.[22] This gap was filled by large adjustments on both the demand and supply sides. Additional supplies from third countries (like Norway, Algeria, and the United States) accounted for 33 percent of the gap, while gas demand in 2022–2023 was about 20 percent lower compared to the 2019–2021 average.[23] Finally, an additional 10 percent of annual consumption was used to increase storage levels, in part necessary because some storage facilities were Russian-owned and had been purposely kept empty. We postpone further discussion of the supply side to section III.E, where we break down the sources of the new gas supplies and highlight the insurance function played by European and global market integration.

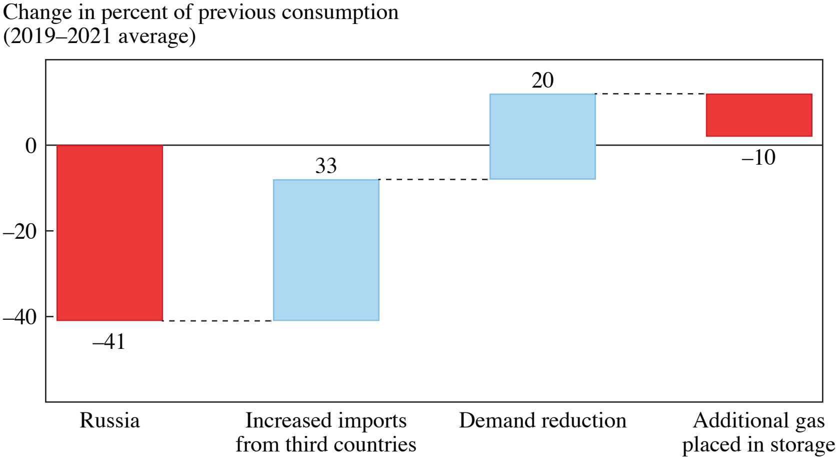
Zooming in on the demand side, table 2 breaks down the 20 percent demand reduction into its key components using data from Ben McWilliams and Georg Zachmann's European Natural Gas Demand Tracker.[24] With the exception of electricity generation, where gas demand for power generation fell only by a small single-digit amount, industrial demand fell by 26 percent and household demand by about 17 percent.

22. This number differs from the 55 percent number in table 1 for two reasons associated with time periods. First, table 1 reports Russian imports as a percentage of average consumption over the whole year, whereas figure 4 reports them as a percentage of average consumption over the nine-month period from July to March. Average gas consumption in the July to March period is higher than over the whole year because it puts a higher weight on the heating period, thus resulting in a higher denominator and lower percentage value. Second, the numerator also differs: table 1 reports Russian gas imports for 2021, whereas figure 4 computes the reduction relative to a time period ending in March 2022. These are different because Russian imports (Yamal and Ukraine transit flows) already dropped considerably in early 2022.

23. On the supply side, we take into account not only direct imports to Germany but also indirect imports via third countries as well as reexports within the European Union. For comparison, online appendix figure B.2 plots the direct flows.

24. Bruegel, "European Natural Gas Demand Tracker," https://www.bruegel.org/dataset/european-natural-gas-demand-tracker.

Figure 4. Germany's Changing Natural Gas Balance



Source: Eurostat (database code nrg_ti_gasm); Ben McWilliams and Georg Zachmann's European Natural Gas Demand Tracker; and Aggregated Gas Storage Inventory (AGSI).

Note: The figure compares German natural gas imports, consumption, and storage change for the period from July 2022 to March 2023 to the corresponding average from 2019 to 2021. On the supply side, we take into account not only direct imports to Germany but also indirect imports via third countries as well as reexports within Europe. More details, including sources, are in online appendix B.

Table 2. Large Demand Reduction by Industry and Households

	(1)	(2)	(3)	(4)	(5)
	2022–2023 consumption (TWh)	*Baseline consumption (TWh)*	*Reduction relative to baseline (TWh)*	*Percentage reduction*	*Hypothetical adjustment (percent)*
Total	642	799	157	20	25
Industry	276	373	98	26	26
Households	281	339	58	17	16
Power	85	87	1	2	45

Source: European Natural Gas Demand Tracker; and Bachmann and others (2022b).

Note: The table summarizes gas consumption over the period July 2022 to March 2023 (column 1) and compares it to average consumption in the same months in the years 2019 to 2021 (column 2). Column 5 refers to predictions about a hypothetical adjustment path made in Bachmann and others (2022b) in early August 2022, ahead of the gas cutoff. The data source provides a more detailed methodology for the calculation of demand, but the key assumptions are as follows: gas consumption is measured separately for so-called RLM meters (large consumers directly connected to the transmission grid) and SLP meters (small consumers). "Households" refers to small consumers (SLP) and therefore also includes commerce and small businesses. "Power" refers to gas used in electricity generation, which we calculate from power output of gas-fired power plants and assuming a plant efficiency of 50 percent. Consumption by industry is calculated by removing gas used for power-generation from RLM consumption. That the numbers in the last row seemingly do not add up is due to rounding.

These numbers are not far off the adjustment path described in our second paper ahead of the gas cutoff (Bachmann and others 2022a), in which we counted on a 26 percent demand reduction by industry and 16 percent by households. However, we substantially overestimated the potential for gas savings in electricity generation. As we will discuss later, this had a lot to do with specific elements of bad luck in electricity generation (the shortfall in French nuclear energy production and the drought in Europe, which reduced available hydropower substantially). The demand reduction was supported by good incentives for savings for households emanating from the proposals of an expert commission, as we will discuss below.

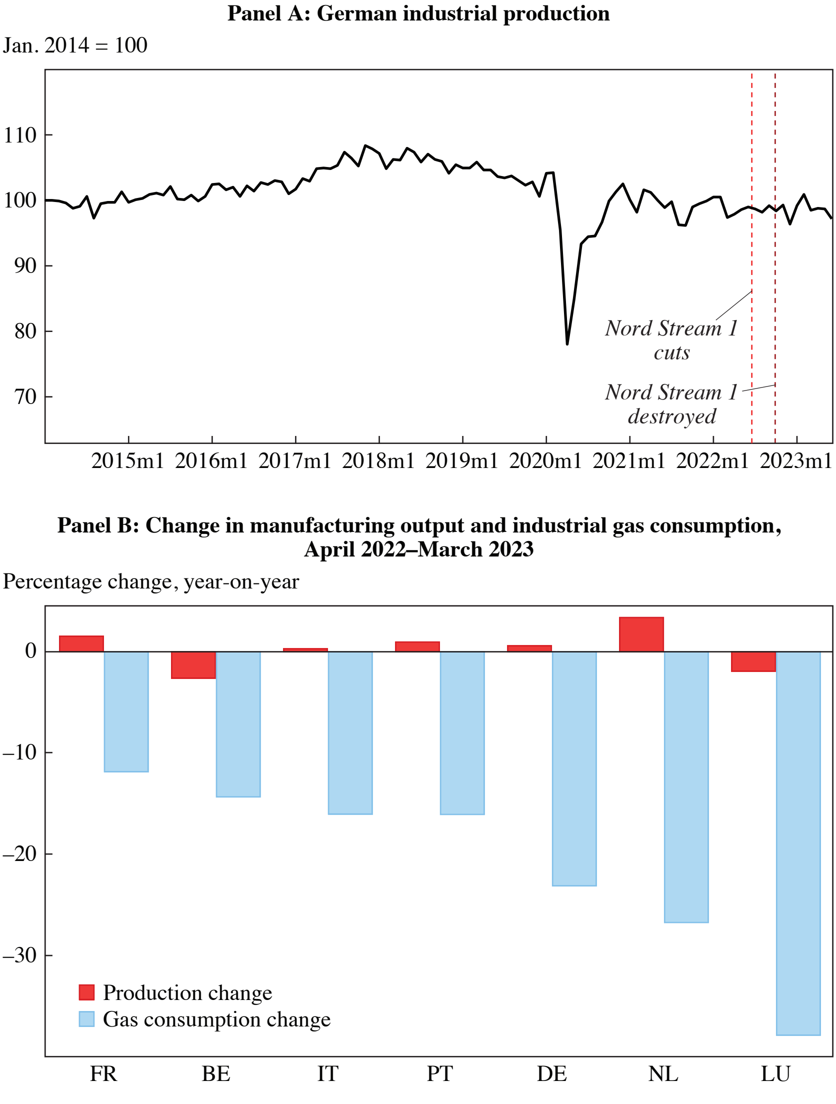
Section II.E emphasized a key sufficient statistic, the change in Germany's gas expenditure share. While our original analysis was forced to speculate about the future evolution of this statistic, online appendix figure B.3 plots this expenditure share using the evidence now at hand. Before the 2021–2022 winter, natural gas accounted for around 1 percent of Germany's total expenditure (GNE). As Russia weaponized and restricted gas supplies, skyrocketing prices meant that this expenditure share increased sharply to around 4 percent of GNE. This quadrupling of the gas expenditure share turned out to be in line with the experiment we described in section II.E and for which the Baqaee-Farhi sufficient statistics approach predicted a 1 percent GNE loss.

III.B. Industry

Taking a closer look at the 20 percent aggregate demand reduction over the past heating period, the evolution of gas consumption and output in the industrial sector is of particular interest as much of the original arguments on the effects of the cutoff focused on the short-run substitutability of gas in industrial production. We already know that, in the aggregate, industrial gas usage decreased by 26 percent relative to previous years (table 2). Importantly, this sharp reduction in gas usage was not accompanied by large output drops, as many had feared.

Figure 5 plots industrial production and gas consumption in Germany and six other European countries. As a benchmark, recall from section II the key prediction that a Leontief zero-substitutability production structure implies that production falls one for one with gas consumption. That is, if elasticities of substitution in industry had been truly zero, Germany should have seen overall industrial production fall by around 26 percent, as the drop in industrial gas usage would have cascaded through the entire supply chain. Figure 5 demonstrates that not only in Germany, but also across the rest of Europe, industrial production looks nothing like this Leontief case.

Figure 5. Industrial Production in Germany and Europe Looks Nothing Like Leontief

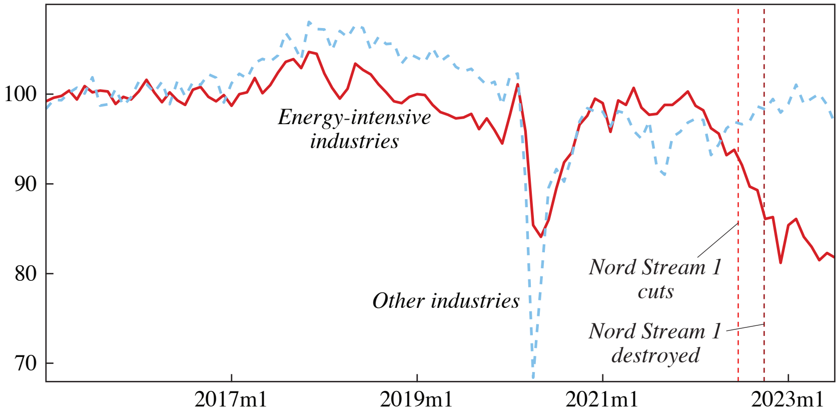


Source: Destatis; European Natural Gas Demand Tracker; and Eurostat.

Note: The industrial production data in panel A are from table 42153-0001 of the German economic sectors statistics, available through the German statistical agency, Destatis, at https://www-genesis.destatis.de/. The index is normalized to 100 in January 2014. Panel B compiles gas demand data for industries from Ben McWilliams and Georg Zachmann's European Natural Gas Demand Tracker, with industrial output data from Eurostat (database code: sts_inpr_m).

Figure 6. Decoupling of Overall Industrial Production from Energy-Intensive Sectors

Production index for energy-intensive industries
2015 = 100; seasonally and calendar adjusted (X13 JDemetra+)



Source: Destatis; and Vogel, Neumann, and Linz (2023).

Note: Data are from Destatis, figure 5, "Bedeutung der energieintensiven Industriezweige in Deutschland" [Importance of energy-intensive industries in Germany]. Energy-intensive industries are: (1) paper and paper products, (2) coke and refined petroleum products, (3) chemicals and chemical products, (4) basic metals, and (5) other nonmetallic mineral products, which together account for a total of 16.4 percent of overall industrial production in the base year 2015 (Vogel, Neumann, and Linz 2023). The index for overall industrial production is a weighted average for energy-intensive industries and for other industries with weights 16.4 percent and 83.6 percent. This allows us to back out the index for other industries from the index for overall industrial production and that for energy-intensive industries.

In Germany, industrial production did not fall meaningfully and even rose compared to the previous year, depending on the month of comparison. On the European level, hardly any correlation can be observed between reductions in gas consumption and manufacturing output. In the Netherlands, for instance, gas consumption fell by almost 30 percent while industrial output overall increased significantly.

We next ask what sectors were most affected by the gas cutoff, and whether and to what extent there were knock-on effects along the supply chain. Unfortunately, the German statistical agency, Destatis, would only release detailed data for 2022 gas usage by industry sector in October 2023. However, we can use preexisting classifications of industries into more and less energy-intensive sectors to gain a better understanding of the actual adjustment processes.

We find clear indications that production in energy-intensive sectors was strongly affected. Figure 6 displays the time path for production in energy-intensive industries using the classification of Destatis alongside production in other industries. As can be seen from the graph, production in energy-intensive sectors dropped by close to 20 percent since gas prices started skyrocketing in early 2022.[25] However, industrial production of other sectors declined only slightly. Importantly, this observed decoupling between energy-intensive production and production of other sectors is the polar opposite of the much-feared cascading effects discussed earlier. Figure 6 (along with the results in figures 7 and 8 below) shows that in an open economy with substitution possibilities, sharp declines in output in some upstream sectors do not necessarily lead to large contractions in downstream industries. At each point in the production network substitution possibilities exist.

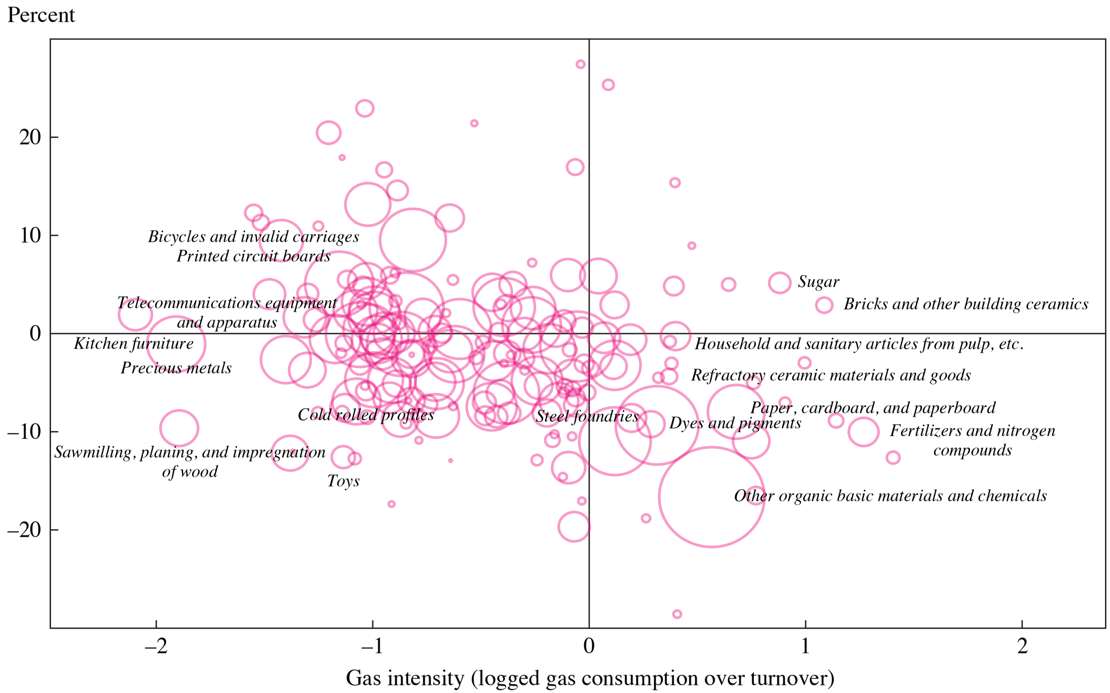
Figure 7 conducts a more granular analysis using our own measure of gas intensity at the sectoral level, with gas intensity defined as an industry's past gas consumption relative to its turnover. As expected, there is a clear negative correlation between changes in industrial production and gas intensity, with the most gas-intensive sectors seeing the largest drops in industrial production. However, not just the slope of the relationship is interesting but also the level. In particular, while energy-intensive sectors like chemicals, paper, and fertilizer did see sharp drops in production (presumably because they also saw substantial drops in gas consumption), many other sectors saw no drops or even increases in production. Instead, in a "cascading-effects view" of the world, industrial production should have fallen in all sectors regardless of how energy intensive they are, because the initial negative gas supply shock to gas-intensive sectors should have taken down the entire supply chain. Figure 7 thus again shows no evidence of cascading effects and instead shows more of the decoupling already evident in figure 6.

When Destatis releases 2022 gas usage by industrial sector in October 2023, it would be interesting to correlate the drops in industrial production in figure 7 with the drops in gas usage. Such a sectoral version of figure 5 (panel B) would provide the sharpest test of the extent of substitution along the supply chain by answering the question: whether production only fell in particular gas-intensive sectors with large drops in gas usage;

25. An interesting question is how close this large production drop in energy-intensive sectors was to the Leontief benchmark of a one for one drop with gas consumption. Since data on gas usage by sector have not been released at the time of writing, we cannot answer this question in this paper. A natural conjecture is that the gas usage in these sectors dropped by more than the 26 percent reduction for industry as a whole, which would imply that not even production in those sectors behaved like in the Leontief case.

Figure 7. Sectoral Output Change and Energy-Intensity of Industrial Sectors

2022 year-on-year change to industrial production, by industry ordered by gas intensity

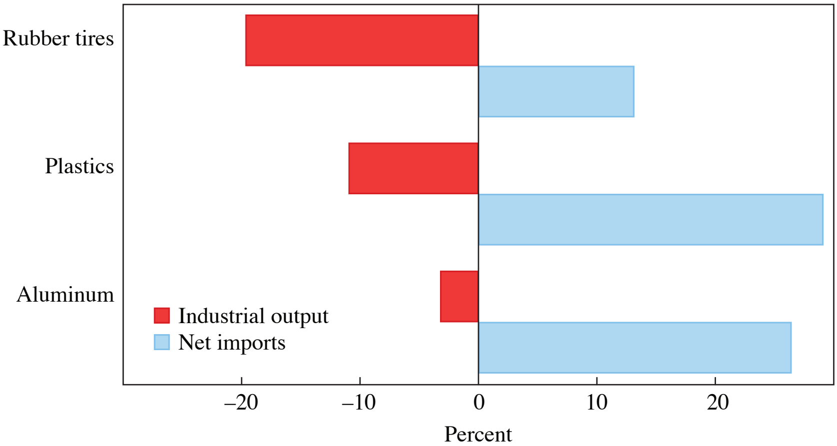


Source: Destatis.

Note: Industrial production and energy consumption data are merged according to Klassifikation der Wirtschaftszweige (WZ) sector codes.

Figure 8. Illustrative Examples of Substitution via Imports

Net imports and industrial output, year-on-year change by sector



Source: Destatis; and Eurostat.

Note: Destatis industry-level data for industrial production are mapped to trade data from Eurostat (database code DS-045409). For rubber tires ("New Pneumatic Tyres, of Rubber") the WZ code for the classification of economic sector by Destatis is 2211 and the Harmonized System (HS) code for global product classification is 4011. For plastics ("Plastics and Articles Thereof") the WZ code is 2016 and the HS code is 39. For aluminum ("Aluminium and Articles Thereof") the WZ code is 2442 and the HS code is 76.

or whether these production drops cascaded further downstream and even affected sectors that do not consume any gas or experienced no drops in gas usage.

Figure 8 provides some illustrative examples for the substitution via imports emphasized in section II.D by plotting output change and import growth for a number of selected energy-intensive industrial sectors like rubber, plastics, and aluminum production. We observe substantial increases in net imports of energy-intensive products. While the correlation with the reduction of output on the industry level is less close, substitution via imports was likely an important channel through which gas savings could be realized with small effects on the overall economy.

A study by Mertens and Müller (2022) provides additional support for the hypothesis that substitution via imports was likely important in practice. Using a more fine-grained product-level analysis, they show that only three hundred specific products account for about 90 percent of industrial gas consumption in Germany. They then argue that these products are heavily traded on the world market and therefore likely more easily substitutable via imports.

As already noted, online appendix E collects thirty-six concrete cases of substitution of gas and gas-intensive products by German firms and households. One of these is worth restating here because it illustrates well the substitution via imports just discussed. When gas prices skyrocketed in Germany and Europe, chemicals giant BASF drastically reduced the production of ammonia (a very gas-intensive product) at its Ludwigshafen site. BASF then switched to producing ammonia in its other plants around the world including in the United States where gas prices were much lower, and more generally, to importing ammonia from other countries. A newspaper article noted that "this substitution via the world market [is] relatively easy" (Höltschi 2022, par. 12).[26] What is worth noting here is that substitution via imports can sometimes even happen *within* the same firm. It is also worth contrasting BASF's apparent substitution prowess with its chief executive's statement about the destruction of the entire economy quoted at the beginning of our paper.

Finally, there is some high-level and suggestive evidence that lower industrial gas demand was, at least in part, due to skyrocketing gas prices—see Ruhnau and others (2023), in particular the downward-sloping time series relationship between monthly prices and quantities in their figure 5(b). The endogeneity of both prices and quantities as well as the complexity of the gas market, mean that this evidence should not be interpreted as causal. But it is nevertheless worth highlighting that high prices were associated with reductions in industrial gas demand.

III.C. Households

Consumption by households and other small consumers represents around 42 percent of overall gas consumption.[27] Because households use gas overwhelmingly for heating, their demand is both highly seasonal and influenced by weather variations (see section IV). Overall, German households consumed 17 percent less gas in the period from July 2022 to March 2023 than in the same period in the three preceding years (table 2).

Online appendix figure B.4 shows that demand reduction by households was significant even when controlling for temperature. While temperature-controlled household demand in January and February 2022 was above

26. See also cases 2 and 15 in online appendix E.

27. As explained in the note to table 2, what we term household gas consumption is consumption by SLP consumers (small consumers not directly connected to the transmission grid), and therefore includes not just households but also some commerce and small businesses.

average, from March 2022, that is, after the war started, it increasingly fell below average. This indicates that households actively reduced their gas consumption. A lot of this saving might have been behavioral, that is, reducing room temperature or heating fewer rooms. But over time we might see more and more structural savings based on investments, ranging from light-touch investments in insulating drafty doors and windows to substantial capital spending on replacing gas boilers with heat pumps.

Disentangling the causes of these quite significant household gas demand reductions will provide important lessons for policymakers and the energy industry. The early demand reductions in March 2022, when high wholesale prices had not yet translated into increasing retail prices, indicate that the shock of the crisis, discussions about emptying gas storages, and public appeals had some effect on household behavior. There was, however, only a very limited federal level gas saving campaign. It had a budget of only 40 million euros—that is, about 50 cents per German citizen—and was targeted at energy switching not at energy saving, and it was not evaluated.[28] This was maybe over worries that a hard savings campaign would rather upset the population (Deutscher Bundestag 2022). More importantly, there was no federal public program to support demand-side investments into gas savings, while at the same time billions were spent on the supply side. On the regional, state, and local levels, campaigns have been run by administrations and gas suppliers.

In general, German retail prices are sticky and billing often happens only once a year. Assessing the impact of retail prices on household gas consumption is held back by a lack of public granular data and has only just begun. Such granular data will be key, as households' exposure to rising gas prices differed widely depending on the region they lived in, their gas suppliers, their gas consumption patterns, and most importantly the supply contracts they were on. As the wholesale price explosion was passed through differently to different customers, the demand reduction patterns might also differ.

Still, over time an increasing share of consumers saw their gas prices go up significantly. All new and renewed retail gas contracts since March 2022 featured significantly higher prices so that more and more consumers were affected by increasing prices over time. By autumn of 2022, a substantial share of consumers had been confronted with drastically increased prices. This visibly impacted demand. Gas prices across countries and

28. The campaign was called "Energiewechsel," which means "energy switch."

changes in gas prices correlate with gas demand reductions during the crisis (McWilliams and others 2022). That is, countries with the highest increase in household gas prices saw the strongest reduction in gas demand in the European Union.

This also shifted the political dynamics for the state to intervene. In September, the federal government set up an expert commission to discuss sensible policies to help consumers without increasing demand (see section III.D), while at the same time temporarily reducing value-added tax for natural gas from 19 percent to 7 percent, muting the price signal for consumers at the expense of German taxpayers (Bundesregierung 2022a).

Analogous to the case of industrial gas demand, there is some high-level and suggestive evidence that high prices were associated with household demand reductions; see Ruhnau and others (2023), in particular the downward-sloping relationship between monthly prices and quantities in their figure 5(a), though with the same caveats as in the case of industrial gas demand (see the discussion above).

III.D. Policy Choices Matter: Germany's Alternative to a Price Cap

Skyrocketing gas prices in the summer and fall of 2022 put substantial strains on the finances of both households and firms, leading to calls for policy intervention to support households and firms. In contrast to policymakers in many other European countries, German policymakers refrained from imposing a price cap on natural gas and instead opted for lump-sum transfers based on households' and firms' historical gas consumption. We briefly review this scheme here for two reasons. First, the scheme is interesting from an economic perspective in that it provides relief by aiming to target the income effect of higher gas prices while leaving substitution effects intact, akin to what Mas-Colell, Whinston, and Green (1995) term "Slutsky compensation." Second, the scheme is an interesting blueprint for future government interventions to alleviate the hardship in the face of rising commodity prices.

The policy was based on the proposal of a commission composed of various stakeholders (such as union and industry leaders) as well as a number of economists, including our coauthors Christian Bayer and Karen Pittel (ExpertInnen-Kommission Gas und Wärme 2022). Precursors of this scheme were proposed by Bayer in Bachmann and others (2022a, 2022b). As has been widely discussed, the official name of the German policy scheme, which translates as "gas price brake," is a misnomer, and "gas cost brake" may instead have been a more accurate name. This is because the scheme caps a household's or firm's total expenditure rather than the marginal price of an extra kWh of gas, which remains equal to the pre-intervention market price.[29]

Figure 9, panel A, graphically illustrates the German scheme using a numerical example. The *x*-axis plots a household's current gas consumption as a percentage of its historical consumption, which is assumed to be 10,000 kWh. The *y*-axis plots the household's gas bill in euros as a function of its gas consumption under a number of scenarios of gas prices and policy interventions. Initially, the gas price paid by households is at 5 cents per kWh, resulting in a gas bill of 500 euros (dash-dotted line). Now gas prices skyrocket by a factor of 5 to 25 cents per kWh so that the gas bill of a household consuming 10,000 kWh of gas is not 500 euros but 2,500 (solid line with circle markers). What are the effects of various policies to support households? One option is a price cap, say at 12 cents per kWh (dashed line). As desired, this brings down the gas bill from 2,500 to 1,200 euros. But it also comes with a problem: it strongly reduces the household's incentive to reduce gas consumption relative to the high price (the dashed line is flatter than the solid line with circle markers).

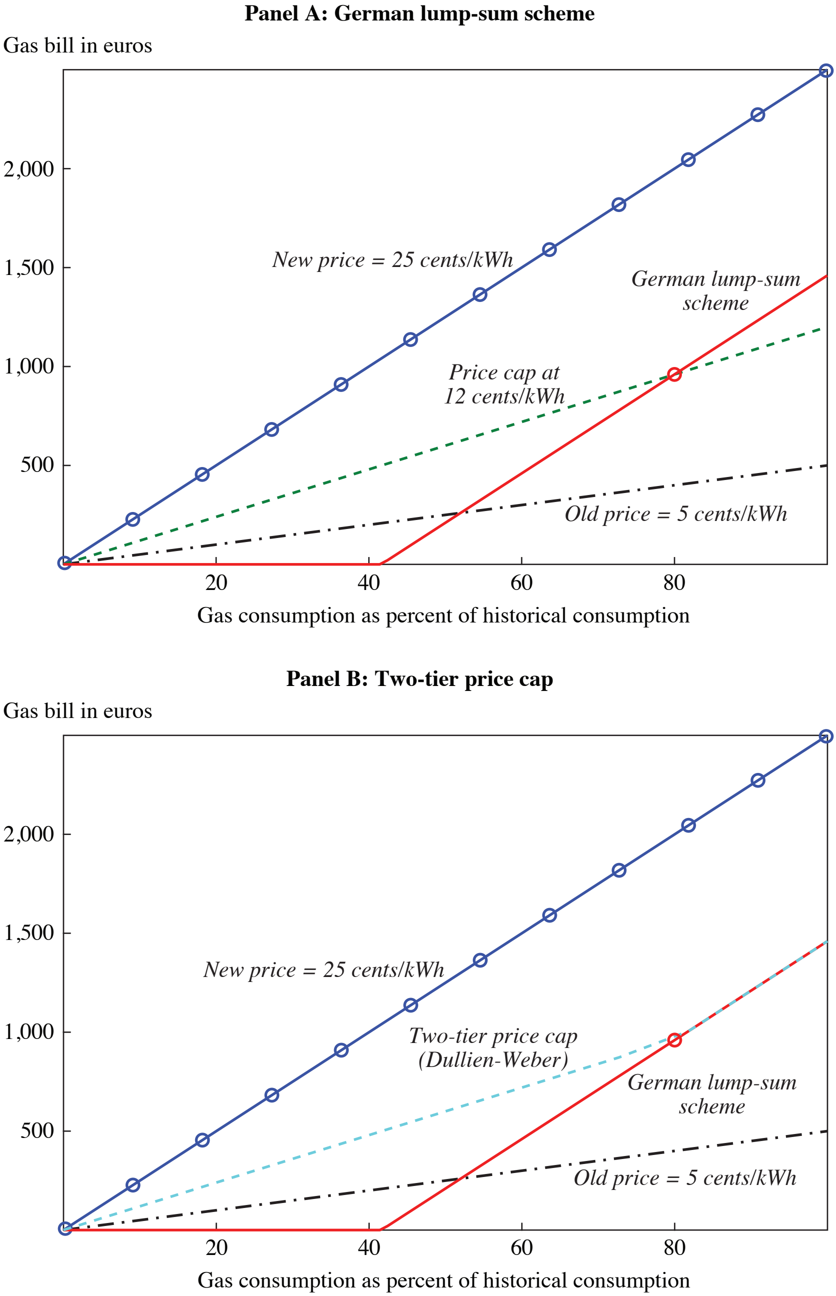
The German policy is represented by the solid line. Households receive a transfer (credit on their gas bill) equal to 80 percent of their historical consumption times the difference between the current market price of 12 cents per kWh (an estimated long-run "new normal" gas price).[30] The key observation is that, in contrast to a price cap, this transfer is not directly tied to current gas consumption (i.e., it is a lump-sum transfer) and thus preserves incentives for reducing gas consumption. Graphically the solid line has the same slope as the solid line with circle markers (though it is everywhere below the latter).[31] By using a household's historical gas consumption as the basis for calculating the size of the transfer, the scheme is nevertheless targeted toward more affected households. Skyrocketing gas prices have both an income and a substitution effect. The income effect is undesirable because it makes households poorer; in contrast, the substitution effect is desirable because it reduces gas consumption. An appealing feature of the German scheme is that it leaves the substitution effect unaffected while

29. See Bayer and others (2023) and Bundesregierung (2023) for summaries and preliminary evaluations of the scheme.

30. Bundesregierung (2022b). The transfer is capped at the total bill amount, that is, it is not possible to make money. Graphically the solid line equals zero when gas consumption drops below about 40 percent of historical consumption.

31. Of course, there *is* a relation between the German scheme (solid line) and a price cap at 12 cents per kWh (dashed line): the point where the two lines cross is exactly 80 percent of past consumption. So the dashed line for the price cap determines how much the solid line is shifted down.

Figure 9. The German "Gas Price Brake" Was a Lump-Sum Transfer and Not a Price Cap



Source: Authors' calculations.

alleviating the negative income effect. The scheme is thus a variant of what the literature has termed "Slutsky compensation" (Mas-Colell, Whinston, and Green 1995). An important point is that the German scheme is not a two-tier price cap, for example, a price cap for 80 percent of past consumption with market prices kicking in for consumption above 80 percent, as proposed by some economists.[32]

Figure 9, panel B, contrasts the two schemes graphically, with the solid line plotting the German scheme (as in panel A) and the dashed line plotting a two-tier price cap with a price cap of 12 cents per kWh for up to 80 percent of past consumption. The key observation is that the schemes differ for any consumption level below 80 percent of past consumption: while the German scheme preserves saving incentives for those who can save more than 20 percent relative to their past consumption, a two-tier price cap reduces these incentives by capping the price faced by consumers. Importantly, households reducing gas consumption by more than 20 percent turned out to be not just an academic curiosity: instead, during the 2022–2023 winter, larger demand reductions were routinely observed.[33]

III.E. New Gas Supplies and the Insurance Value of European Integration

As shown in figure 4, additional supplies of non-Russian gas to Germany played an important role in getting Germany through the 2022–2023 winter, with these imports increasing by around 33 percent relative to previous consumption. This section breaks down these imports further and highlights two main channels. First, additional gas imports into Europe made their way to Germany via the integrated European pipeline network. Second, demand reduction elsewhere in Europe freed up gas supplies that then ended up in Germany. Both channels underscore the insurance benefits of global and European market integration (Caselli and others 2019).

Considering Europe as a whole, gas imports increased significantly, with most of this increase coming from LNG, which increased by 470 TWh in the period after the Nord Stream cuts (July 2022 to March 2023), compared

32. See, for example, Dullien and Weber (2022).

33. While the average household demand reduction over the entire 2022–2023 winter was less than 20 percent (see table 2), demand reductions in particular weeks were considerably above 20 percent and often up to 40 percent. See Bundesnetzagentur, "Gasverbrauch Haushalts- und Gewerbekunden, wöchentlicher Mittelwert" [Gas consumption households and businesses weekly], https://www.bundesnetzagentur.de/DE/Gasversorgung/aktuelle_gasversorgung/_svg/GasverbrauchSLP_woechentlich/Gasverbrauch_SLP_W_2023.html. The same is presumably true for particular households or geographic areas.

to the 2019–2021 average and a more moderate contribution from pipeline imports, which increased by 110 TWh.[34] An important feature of the additional LNG imports was that they came at extremely high prices. Because global production capacities as well as the infrastructure for transporting LNG were constrained, LNG destined for other markets had to be rerouted to Europe by offering extremely high prices for individual cargoes. The small increase in pipeline imports to Europe was similarly due to the fact that production and transportation capacity could not be ramped up more quickly.

Turning to Germany individually, online appendix figure B.1 plots a version of figure 4 but with the imports from third countries broken down by ultimate source country. The largest supplier of additional non-Russian gas was Norway, contributing additional imports worth around 16 percent of previous consumption, that is, almost half of the 33 percent overall additional supplies. LNG imports were also important, contributing a combined total across all countries of 13 percent. Note that, like figure 4, the figure takes into account not only direct imports to Germany but also indirect imports via third countries as well as reexports within the European Union. This is particularly important for LNG because Germany had rejected building any LNG import infrastructure prior to the crisis and therefore had to rely instead on LNG terminals elsewhere in Europe (e.g., in Belgium, the Netherlands, and France) for most of these imports. Immediately following the Russian invasion, Germany put in motion plans finally to build LNG terminals on its coast. These made a small contribution of gas imports worth around 3 percent of previous consumption (see online appendix figure B.2).[35] The important role of gas imports from third countries, and specifically via other European countries, highlights the insurance benefits of global and European market integration.

While imports from outside Europe were instrumental for displacing Russian gas in Germany, another crucial factor for getting Germany through

34. The series for European LNG imports includes indirect imports of LNG via the United Kingdom that were then passed by pipeline into the Netherlands and Belgium. The UK pipeline flows to the Netherlands and Belgium dramatically increased to make use of extra LNG import capacity in the United Kingdom. In Europe as a whole, 20 percent of LNG import capacity was added in 2022:Q4 and 2023:Q1. See Bruegel, "European Natural Gas Imports," https://www.bruegel.org/dataset/european-natural-gas-imports.

35. The contribution of the newly built LNG terminals may seem small to readers who are familiar with the German gas debate given these were often touted as "game changers" by politicians and the media. The reason why their contribution to getting Germany through the 2022–2023 winter was not larger is that they only came online relatively late, with the first LNG terminal (Wilhelmshaven) opening on December 17, 2022.

the 2022–2023 winter was the demand reduction elsewhere in Europe. This is because additional imports to Europe replaced only about two-thirds of Russian imports so that an additional fall in demand was needed.[36] In the European Union as a whole, gas demand declined by a substantial 18 percent or 630 TWh in the period from July 2022 to March 2023 compared to the 2019–2021 average.[37] Gas consumption fell substantially not only in countries that were highly dependent on Russia but also in others that were not. This freed up additional gas supplies for those countries most in need. A political commitment to reducing gas consumption by at least 15 percent (European Commission 2022) likely contributed to this EU-wide demand reduction, specifically because it entailed a commitment to letting markets work despite the very high prices that were adversely impacting domestic industrial and household consumers alike. In summary, high prices discouraged demand all over the European Union, high prices at the entry points into the European system drew international volumes into Europe, and intra-European gas price differentials pulled gas flows into the countries most in need of volumes to replace Russian supplies, specifically Germany.

III.F. Looking Back and Looking Ahead

With the benefit of hindsight, which elements of our earlier analysis have held up well and which ones less so, that is, where is there room for improvement? What lessons can we draw for future analyses of similar scenarios? For example, suppose that ten years from now another large energy supply shock looms and we would like to evaluate it using quantitative macroeconomic modeling. Or suppose China invades Taiwan and a similar debate arises about the economic costs of sanctioning China. Which parts of the analytical framework described earlier will come in handy, and where does it have gaps?

In retrospect, probably the biggest gap in our earlier analysis was the omission of demand-side effects, in particular standard Keynesian aggregate demand amplification: rising energy prices drag down consumer spending and this feeds back into production and employment, which further drags down consumption, and so on.[38] Direct empirical evidence for this type of Keynesian multiplier mechanism is hard to come by because it is

36. Bruegel, "European Natural Gas Imports," https://www.bruegel.org/dataset/european-natural-gas-imports.

37. Bruegel, "European Natural Gas Demand Tracker," https://www.bruegel.org/dataset/european-natural-gas-demand-tracker.

38. As noted in section II.F, our model did include the standard flexible-price demand-side effect that higher energy prices erode purchasing power and erode consumer welfare.

concerned with general equilibrium effects and we have not come up with a convincing empirical strategy for isolating them during this particular episode.

However, there are two reasons to believe that such effects are important in practice and should be included in full-blown analyses of negative energy supply shocks. First, this mechanism is operational in standard macroeconomic models with nominal rigidities that are consistent with empirical evidence on household consumption behavior, in particular HANK models that are consistent with the large observed marginal propensities to consume.[39]

Second, empirical analyses of past energy shocks (typically oil shocks) using time series data have documented patterns consistent with demand-side effects, in particular that these shocks primarily affected the economy through a disruption in consumer spending on goods and services other than energy (Hamilton 2008, 2009, 2013; Edelstein and Kilian 2009). For example, Hamilton (2009, 2013) shows that one of the key responses seen following the five historical oil shocks was a decline in car purchases, and argues that this accounted for a large share of the drop in GDP in the five quarters following the shocks. Hamilton (2013, 262) concludes that "combining these changes in spending with traditional Keynesian multiplier effects appears to be the most plausible explanation for why oil shocks have often been followed by economic downturns." If such demand-side amplification was important following the past oil shocks, one would expect it to also have been operational following the German economy's cutoff from Russian gas.

An interesting question is why Germany's 2022 cutoff from Russian gas appears to have been less costly than the oil shocks of the 1970s.[40] Three candidate explanations are as follows. First, both in the 1970s and today, oil plays a more important role in the global economy than natural gas, and therefore, the oil shocks were simply larger shocks. To show this, online appendix figure B.5, panel (a), compares the evolution of world oil expenditures as a share of world GDP to those on natural gas since the 1970s.

39. See Bayer, Kriwoluzky, and Seyrich (2022), Bayer and others (2023), Pieroni (2023), and Auclert and others (2023) for analyses emphasizing this mechanism.

40. It is worth noting that during the 1970s oil shocks, Germany fared better than the United States. For example, in the aftermath of the 1973–1974 oil shock, US GDP contracted by 2.5 percent (Hamilton 2009) whereas German GDP contracted by only 0.9 percent in 1975; Destatis, "Bruttoinlandsprodukt von 1950 bis 2022 im Durchschnitt 3,1 % pro Jahr gewachsen" [Gross domestic product grew an average of 3.1% per year from 1950 to 2022] https://www.destatis.de/DE/Presse/Pressemitteilungen/2023/06/PD23_N032_81.html.

Despite larger fluctuations in both series, the oil expenditure share is consistently higher than the gas expenditure share, with oil expenditures of about 2 percent of GDP in normal times compared to 1 percent for gas. Similarly, comparing the 1970s oil and 2022 gas shocks, oil expenditure more than quadrupled from about 1.5 percent to 7 percent of world GDP in the 1970s, whereas gas expenditure rose from around 1 percent to 3.5 percent—the oil shock's peak impact was again twice as high as that of the gas shock (7 percent versus 3.5 percent).[41] Data for both Germany and the European Union as a whole paint a similar picture—see online appendix figure B.5, panel (b).[42] Tying this back to our earlier theoretical discussion, we showed in section II.A that economic costs of input supply shocks not only critically depend on the elasticity of substitution but also on the share parameter. Specifically, we showed there that (keeping $\sigma = 0.05$) an oil value for α equal to 2 percent yields output losses of 4.5 percent, which are almost twice as high as those with a gas value for α equal to 1 percent. That is, we should a priori expect the economic costs of oil shocks to be almost twice as high as those of the gas cutoff simply because the oil expenditure share is roughly twice that of gas.

Second, as noted in section II.D, structural change means that manufacturing now accounts for a smaller share (only about a quarter) of economic activity than in the past. Third, households' use of oil and gas differ in ways that could explain why high oil prices appear to be a stronger drag on consumer spending than high gas prices. Specifically, high oil prices affect consumers primarily via high petrol prices, whereas high gas prices affect heating costs. Petrol prices are much more closely tied to spot market prices than heating costs, which are determined by relatively longer-term contracts. Petrol costs are arguably also more salient and may thus affect consumer spending and confidence more strongly.[43]

41. Note that the oil shock was also much more persistent. Consistent with our numbers, Baqaee and Farhi (2019, fig. 7) calculate that the global expenditure on crude oil as a share of world GDP was around 2 percent and quadrupled to 8 percent in the 1970s.

42. Also recall online appendix figure B.3, which showed an increase in Germany's gas expenditure share in GNE from 1 percent to 4 percent. The larger impact for Germany in figure B.3 than in figure B.5, panel (b), is primarily due to the use of higher frequency monthly data in figure B.3, with monthly gas prices showing a larger peak than the yearly data in figure B.5, panel (b).

43. Finally, a potential alternative explanation is that many oil shocks appear to be strongly temporally correlated with large monetary policy shocks (Hoover and Perez 1994; Nakamura and Steinsson 2018), implying that inference about the separate effects of either type of shock is complicated.

On the flip side of paying more attention to Keynesian demand amplification, future analyses should probably spend relatively less time and effort quantifying the cascading effects discussed in section II.D. This is because the data instead showed a substantial decoupling of overall industrial production from that in a few energy-intensive sectors like chemicals and glass, the polar opposite of cascading effects. The focus on cascading effects in our original paper (Bachmann and others 2022b) was due to these effects being a central (or perhaps even *the* central) concern in the German public debate back in the spring of 2022. In retrospect, this also reflected that lobbyists are skilled at shifting public debates, in particular, taking advantage of the fact that the "Leontief logic"—everything drops proportionately—is extremely intuitive for nonspecialists. The absence of cascading effects and the strength of the observed decoupling between energy-intensive production and the rest is interesting from an economic perspective. Once more, when the granular data on industrial production and gas usage become available, it would be interesting to see how exactly this decoupling played out in practice.

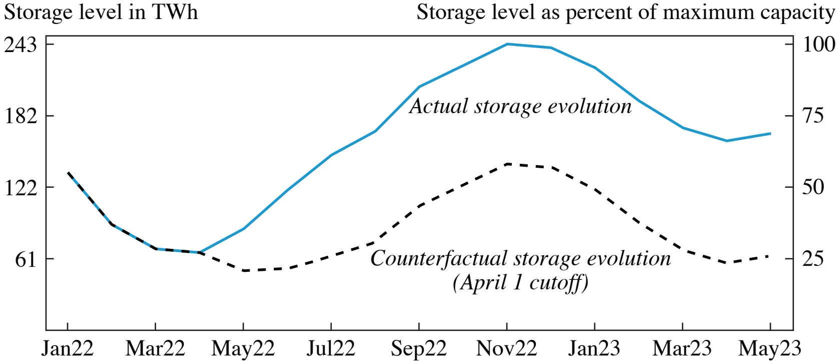
IV. Could Germany Have Withstood an Earlier Cutoff as Well?

To what extent did the timing of the cutoff matter for these benign economic outcomes? It is clear now that the cutoff from Russian gas that Germany experienced in the summer of 2022 had moderate and manageable economic consequences, and that the country even exited the winter with substantial gas reserves of around 65 percent (see figure 10 below). But it is an open question whether Germany would have made it through the winter with an earlier cutoff, possibly as early as April 2022, which would have left only a few weeks for preparations.

A prominent line of argument is that the additional months from April to August, during which Germany continued to import and stockpile Russian gas, were decisive to fill storage capacity sufficiently to get through the winter. Without those Russian imports, the argument goes, with an immediate severance from Russian energy starting in April 2022, shortages, rationing, and high economic costs would have ensued.

We here provide some simple counterfactual calculations to answer this question, taking April 1, 2022, as the hypothetical cutoff date. We ask the following simple questions: In retrospect, would Germany still have had gas left in its gas storage facilities at the end of the 2022–2023 winter if the country had stopped importing Russian gas on April 1, 2022, rather than

Figure 10. Counterfactual Storage Evolution with Gas Cutoff at the End of March 2022



Source: Bruegel; and authors' calculations.
Note: See online appendix C for details on sources and the construction of the series for counterfactual storage evolution.

continuing to import and stockpile Russian gas until the end of August 2022? Or would Germany have run out of gas in the middle of the winter?

Figure 10 presents a simple counterfactual scenario that answers this question. The solid line plots the actual observed storage evolution including Russian gas imports after March 2022. The dashed line plots the counterfactual storage evolution in the event of an April import stop calculated from combining data on Russian gas imports and the observed storage evolution (see the explanation below and in the online appendix). The key takeaway is that even with an April 1 gas cutoff, Germany would still have exited the winter with gas storages that are 25 percent full. In other words, Germany would have been able to cope with an earlier April embargo.

The following simple calculation explains this result. We compute the cumulative observed imports of Russian gas over the period from April to August 2022, taking into account imports via third countries as well as reexports (see online appendix for details) and compare this number to the amount of gas left in German storages at the end of the 2022–2023 heating period. The idea is simple: holding consumption and other gas supplies constant, if Germany exited the winter with more gas left in its storages than these cumulative imports, then Germany would not have run out of gas even with an April import stop from Russia; in contrast, if gas reserves at the end of the winter were less than these cumulative imports, Germany may have run out of gas without these imports.

Germany had imported about 100 TWh of Russian gas since April 2022, which is about 10 percent of the typical annual gas consumption in previous years or about 40 percent of maximum storage capacity.[44] On the other hand, Germany had about 160 TWh of gas left in its storage facilities, which is about 16 percent of typical annual consumption or about 65 percent of storage capacity. Therefore, even with an April 1 gas cutoff, Germany would still have emerged from the winter with gas storages that were 25 percent full (65% – 40% = 25%), which is exactly the number plotted in figure 10—see the data point for April 2023.

In fact, the 25 percent storage level implied by this simple counterfactual calculation should be viewed as a lower bound, that is, Germany would have arguably emerged from the winter with higher gas storage levels. First, our counterfactual calculation holds constant German gas consumption, that is, it assumes that even with gas supplies falling much more substantially and storage levels being considerably lower before the start of the winter, consumption would have been unchanged relative to its actual time path. This assumption is unrealistic: instead, with lower supplies and storage levels, further demand reduction would likely have occurred.[45] Second, there was a time period in October and November 2022 during which German gas storages were virtually full and therefore gas imports were constrained by a lack of storage capacity—nowhere to put this gas. In fact, gas storages not just in Germany but all over Europe were so full at this point that this resulted in large numbers of LNG tankers queuing off Europe's coasts, unable to unload.[46] While our calculation provides a lower bound on gas storage levels at the end of the 2022–2023 winter, we view it as useful because of its simplicity.

44. For Germany-wide maximum storage capacity we use 246 TWh, based on the fact that storages were completely filled by early November 2022 with 246 TWh. Similarly, there is a question as to what the minimum storage level is at which storages can still operate efficiently. The lowest historical storage filling level was only 35 TWh of working gas in March 2018, significantly below the 60 TWh in our counterfactual scenario, and even at 35 TWh storages still contained significant volumes of cushion gas that could have been extracted in an emergency situation; Gas Infrastructure Europe (GIE), "Aggregated Gas Storage Inventory (AGSI) Data Overview," https://agsi.gie.eu/data-overview/graphs/DE.

45. This mechanism, additional demand reduction, would have likely been a particularly powerful force toward higher storage levels. This is because German gas storages are small relative to typical gas demand: maximum gas storage capacity is 246 TWh, which is only about a quarter of annual gas consumption of about 1,000 TWh (Bachmann and others 2022a). Thus, even an additional demand reduction of only 2 percent would have reduced demand by 20 TWh and would have increased the storage filling level at the end of the winter from 60 TWh or 25 percent to 80 TWh or 33 percent.

46. See, for example, Rashad and Carreño (2022) and LaRocco (2022).

To construct the full time path for counterfactual storage evolution in figure 10, we further break down imports of Russian gas by month. Online appendix figure C.1 plots the results and highlights that, while Germany continued to import Russian gas through the end of August 2022, these imports were small from June onward when Russia started weaponizing gas.[47] Using these monthly data, figure 10 is then computed by subtracting the Russian imports for each month from the observed storage net inflows. Apart from our main argument that Germany would have not exhausted its gas reserves at the end of the 2022–2023 heating period, figure 10 makes another important point, namely, that gas storages are also not exhausted at any other point in time after April 2022. Put differently, the combination of gas imports from other countries and preexisting storage would have been sufficient to satisfy both industrial and household gas demand at any point in time.

In particular, contrary to the arguments of some skeptics, there was never a danger of a gas shortage immediately following an April gas cutoff. One important reason for this result is the well-known seasonality of gas demand—that gas demand is much lower in the summer. An April cutoff would have coincided with the end of the 2021–2022 heating period and thus the start of the low-demand summer period, meaning that even relatively low levels of preexisting storage would have been enough to prevent shortages and rationing. That the seasonality of gas demand means that there would be no immediate gas shortages even with a cold turkey import stop was an important argument in Bachmann and others (2022b).[48]

Although we focus on the outcomes in Germany, our counterfactual scenario considers a cutoff from Russian gas for the European Union as a whole rather than just Germany. Because the European gas market is complex and heavily interconnected, we therefore take into account not only direct imports to Germany from Russia (via the Nord Stream 1 pipeline) but also indirect imports via third countries (e.g., flows via Ukraine Transit and Czechia or Austria to Germany) as well as reexports. Thus, our series for imports from Russia includes only the gas that actually entered and was consumed or stored in Germany and would have been therefore "missing"

47. Thus, the skeptics' argument that the additional five months from April to August, during which Germany continued to import and stockpile Russian gas, were decisive for getting the country through the following winter is really an argument about two months alone, April and May.

48. Of course, an earlier import stop would likely have moved gas prices by more or earlier, or both. This would have likely resulted in higher economic costs. On the flip side, it would have also resulted in larger demand reduction as already discussed.

in the event of an earlier import stop. Our counterfactual scenario then subtracts these missing imports from total net inflows into German storages. Note that the subtracted missing imports do not include Russian gas that used to be reexported to third countries because doing so would overstate the gas shortfall by effectively assuming that, after April 1, Germany would have just reexported the same amount of gas as if nothing had happened despite being cut off from Russian gas. The online appendix contains details and discusses a number of additional considerations.

V. The Role of Luck

In any year, gas supply and gas demand are affected by numerous exogenous factors whose unpredictable realizations can noticeably ease or tighten the supply-demand balance. The most important factor is the weather (section V.A), but there are also many other important variables like accidents, strikes, and conflicts, specifically those affecting the European electricity market (section V.B), as well as the availability of LNG, which played an important role in displacing Russian gas (section V.C).

V.A. Was the 2022–2023 Winter Particularly Warm?

Heating demand and hence temperature is a main driver of gas demand in Germany. If on one cold day the average temperature falls by 1°C, the total daily gas consumption in Germany will increase by about 165 GWh. This means that, on a day with a temperature of 0°C, a 1°C change corresponds to 6–7 percent of gas consumption. Most of this temperature sensitivity of demand is due to small and household consumers.[49]

At a very basic level, the average winter temperature for Germany in the 2022–2023 winter of 2.9°C was actually slightly colder than the average temperature of 3.0°C over the four previous winters.[50] However, a more systematic analysis is required. To account for the fact that when it is already warm outside, heating demand is relatively unresponsive to temperature changes (say from 20°C to 21°C daily average), energy economists like

49. About 120 GWh higher demand per degree comes from small consumers alone in Germany on average. Numbers here are authors' own calculations based on the Eurostat data of sectoral gas demand and heating degree days.

50. Deutscher Wetterdienst, "Zeitreihen für Gebietsmittel für Bundesländer und Kombinationen von Bundesländern" [Time series for area averages for federal states and combinations of federal states], https://opendata.dwd.de/climate_environment/CDC/regional_averages_DE/seasonal/air_temperature_mean/regional_averages_tm_winter.txt; accessed via "Mittelwerte für die einzelnen Bundesländer und für Gesamtdeutschland," https://www.dwd.de/DE/leistungen/cdc/cdc_ueberblick-klimadaten.html.

to use heating degree days (HDDs). HDDs are a measure of the severity of the cold (specifically, how much the outside temperature is below 18°C) and hence the need for heating over a specific time period. Figure 11, panel A, shows that monthly HDDs are almost perfectly correlated with monthly gas consumption.

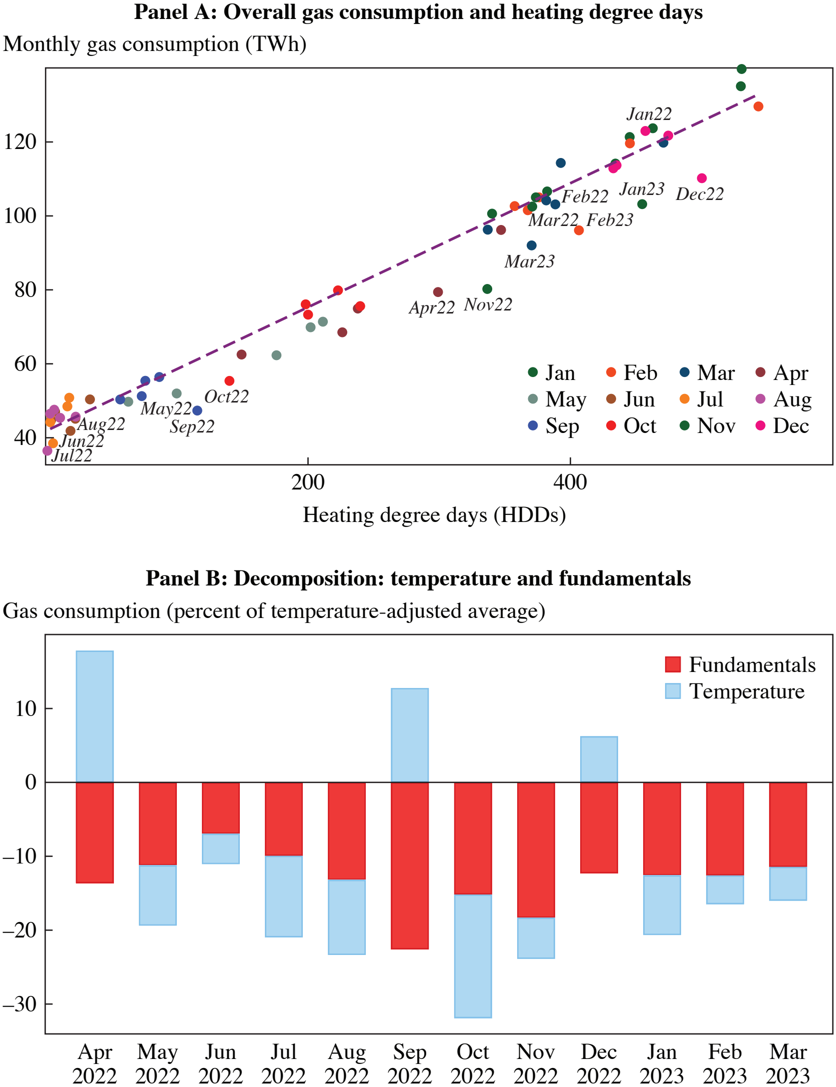
Figure 11 also shows that, following the Russian invasion of Ukraine (i.e., from March 2022), all monthly gas consumption fell below the linear trend that indicates the expected gas consumption given a month's HDDs. For example, December 2022 was particularly cold and showed a high number of 500 HDDs (in the previous five years, December had between 433 and 475 HDDs), which would normally imply 123 TWh of gas consumption. However, despite these cold temperatures, in December 2022 Germans consumed only 107 TWh.

Overall, the year 2022 had 2,736 HDDs in Germany. This can be compared to three different baselines. First, comparing it to the previous year 2021 with 3,114 HDDs makes 2022 look like a warm year. But 2021 was actually the coldest year since 2013 (as measured by HDDs), meaning that 2021 was an outlier. Second, one can compare it to the average of the previous decade of 2,933 HDDs per year. But this decadal average is not a good measure of the expected number of HDDs for 2022 either. The reason is climate change. Our third and preferred comparison accounts for this trend: using data since 1979, online appendix figure D.1 shows that the number of HDDs declined by about 14 HDDs every year. Along this long-term trend line, the expected number of HDDs in 2022 was about 2,850. Thus, with 2,736 HDDs, the year 2022 had only 114 fewer HDDs (the year was slightly less cold as measured by HDDs). Converting these 114 HDDs into gas consumption using the correlation in figure 11, panel A, implies a reduction in gas consumption of only 18 TWh or 1.8 percent of average consumption. Hence, as measured by HDDs and the implied gas demand, Germany was not particularly lucky.[51]

Taking this logic one step further, we can also decompose the observed reduction in gas consumption into a part due to temperature and another part due to "fundamentals" (i.e., factors other than temperature). For example, a baseline year with 2,850 HDDs would have implied a gas demand of 996 TWh. Compared to that, Germany's 2022 consumption of 854 TWh implied a demand reduction of 142 TWh. Hence, the 18 TWh savings from slightly milder temperatures accounted for less than 13 percent of

51. On the flip side, it is true that Germany was also not particularly unlucky. For example, a very cold winter like 2021 would have increased gas consumption by about 61 TWh.

Figure 11. Temperature-Adjusted Gas Consumption



Source: Bundesnetzagentur; and Eurostat.

Note: Gas consumption data are from Bundesnetzagentur, "Gasverbrauch Haushalts- und Gewerbekunden, wöchentlicher Mittelwert" [Gas consumption households and businesses weekly]. Data on heating degree days (HDDs) are from Eurostat (database code nrg_chdd_m). HDDs are a measure of the severity of the cold, specifically, how much the outside temperature is below 18°C, and hence the need for heating. In panel A, the line is fitted using data up to March 2022. In panel B, the reduction in gas consumption compared to the pre-2022 average is decomposed into two parts. The term "fundamental" represents the difference between actual gas consumption and its predicted value from the fitted line, while the remainder is called "temperature."

the savings, that is, the remaining 87 percent were due to fundamentals. Figure 11, panel B, uses the correlation in panel A to conduct a similar exercise for each month in the period from April 2022 to March 2023. The results show that in all but one month, mild temperatures played a minor role in accounting for reduced gas consumption (the exception is October 2022). In fact, both September and December 2022 were unusually cold but nevertheless saw substantial gas savings. These calculations confirm the results by Ruhnau and others (2023) and Roth and Schmidt (2023), who find that substantial savings happened even after controlling for temperature.

Finally, the warmer temperatures in October and November 2022 contributed disproportionately little to getting Germany through the winter. This is because the warmer temperatures (smaller number of HDDs) occurred at a time when gas storages were virtually full. Hence, higher temperatures in October and November resulted in lower gas prices but not a better preparation for the coming winter.

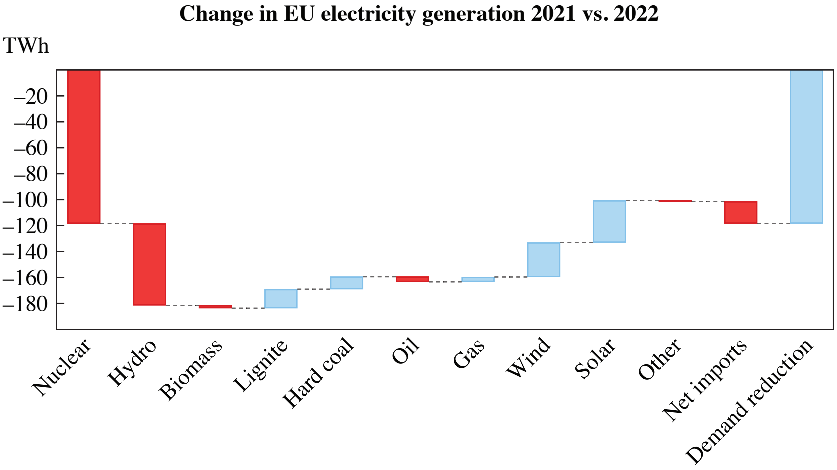
V.B. Shortfalls in Electricity Generation Prevented Fuel Switching

Different energy commodities show strong interactions. This is particularly true for natural gas and electricity. The two are direct substitutes for producing heat and a significant share of electricity is produced from natural gas. Their demand has many common drivers like weather and economic activity. Moreover gas and electricity demand and prices interact indirectly through other commodity markets, especially those for emission allowances and coal. Most importantly, even though gas-fired power plants are a relatively expensive and inefficient way of producing electricity, there are many hours each day during which electricity production relies on natural gas simply because cheaper options alone are insufficient to meet demand. Notably, because one needs about two MWh of gas to produce one MWh of electricity, the marginal cost and hence the hourly wholesale electricity price per MWh in these hours is about twice the gas price per MWh. Accordingly, developments in the gas market spill over into the wholesale electricity market, which has roughly the same annual turnover.

This high degree of interaction has two relevant implications: First, gas savings may be achieved via fuel switching in electricity production (e.g., from gas to oil or coal) or via reduced electricity consumption. Second, high gas prices have a very strong impact on electricity prices.

In 2022, however, special conditions in electricity markets meant that the first effect did not actually contribute to mitigating the gas crisis. Maintenance issues at French reactors meant that French nuclear generation in

Figure 12. Reduced Ability of the Electricity System to Alleviate the Gas Scarcity



Source: Energy-Charts.
Note: Data are based on European Network of Transmission System Operators for Electricity (ENTSO-E).

2022 was 82 TWh (or 22 percent) below the already low 2021 values. Moreover, the long-planned shutdown of three German reactors at the end of 2021 reduced power generation by 32 TWh and a drought reduced hydro generation in the European Union by 82 TWh compared to 2021. Reduced nuclear and hydro generation in 2022 meant that the European Union lacked about 180 TWh (7 percent) of its low-cost electricity supplies (see figure 12). Replacing this electricity production shortfall with gas-fired generation—which is often the marginal fuel in the northwest European power market—would have required burning about 360 TWh more natural gas in power plants.[52] As a result, the European electricity system, which would normally have served as a substantial buffer to gas supply issues by switching to using more coal and reducing electricity demand, was already extremely stretched due to its own internal problems. Therefore, despite the largest gas crisis in recent history, Europe actually increased gas consumption in the power sector slightly from 432 TWh to 436 TWh instead of decreasing it as predicted by economic theory.[53] These elements of

52. As gas-fired power plants have an efficiency of about 50 percent in transforming the heating energy of natural gas into electric energy, it takes about 400 TWh of gas to produce about 200 TWh of electricity.

53. The data on electricity generation used in this paragraph are from Energy-Charts.

bad luck also explain the very small contribution of power generation to demand reduction in Germany in table 2.

V.C. The Role of LNG

Whether the situation in global LNG markets was favorable to weathering the gas cutoff is a difficult question. It is clear that massive EU LNG imports induced higher global LNG prices and hence triggered supply extension and demand reduction in other markets. But whether lower Asian gas demand in 2022 was driven primarily by unexpected local factors (e.g., the slower than expected post-COVID-19 recovery) or whether this low demand was a reaction to the very high LNG prices is hard to disentangle empirically.[54]

Moreover, in June 2022, the Freeport LNG plant in the United States, the fourth-largest LNG liquefaction plant in the world, was put out of action by a fire and only restarted loading cargoes in mid-February 2023. Had it not been dysfunctional, this plant would have been able to liquify more than 100 TWh of US natural gas.[55]

In conclusion, the bad luck elements actually exceeded the good luck ones over the last year. The role of good luck in getting Germany through the winter has been considerably overstated in the popular debate.

VI. Political Economy of Decision Making in Times of Crisis

Some of the most important lessons from the great German gas debate concern the political economy of decision making in times of crisis. While some of these lessons are linked to specific features of the German corporatist model of close coordination between government, business associations, and trade unions, others likely extend beyond the narrow German context and are important to be reflected upon. In particular, the tensions between China and Taiwan could well lead to comparable developments where policymakers might have to navigate similar trade-offs between business interests and foreign policy objectives. In the German case, the most

54. Asian LNG imports decreased from 273 MT LNG to 252 MT LNG, whereby China alone reduced by 16 MT according to GIIGNL (2023).

55. Freeport has a liquefaction capacity of about 20 billion cubic meters per year, hence more than 100 TWh in the eight months of its dysfunctionality. Enerdata, "JERA Will Buy 25.7% of the Freeport LNG Project (US) for US$2.5bn," November 17, 2021, https://www.enerdata.net/publications/daily-energy-news/jera-will-buy-257-freeport-lng-project-us-us25bn.html.

important insights have to do with the outsized role of business leaders and their associations in times of acute crisis. One does not have to agree with Adam Smith's (1776, 16) famous quip that congregations of businessmen often end in a "conspiracy against the public" to conclude from the recent experience that geopolitical dynamics can bring specific incentive problems for profit-maximizing business leaders.

When the discussion about Germany's vulnerabilities began after the Russian invasion, policymakers did not turn to academics but to business leaders and their associations for advice. The key interlocutors were representatives of the most affected industries such as the energy and chemicals sectors, refineries, and other industrial companies. This was primarily due to policymakers' concern to understand the practical implications of a cutoff from Russian gas and what this would mean for operations "on the ground."

While understandable, this also meant that the very industries that had made large commercial bets on Russian gas became the main interlocutors, thereby blurring commercial interests and political influence once again. Business leaders had a clear incentive to talk up the dependence on Russian gas in their interaction with policymakers in Berlin, thereby making a stronger political and military reaction by the German government less likely and indirectly increasing the chances of continued access to cheap Russian gas for their companies. Most CEOs and leaders of industry associations were outspoken that the consequences of a cutoff from Russian gas would be catastrophic. The feedback was that the dependence was extremely high, and that in the short run, no alternatives existed so that production cuts coupled with cascading effects down the production chain would be inevitable consequences of a gas cutoff. Union representatives, mainly concerned with potential job losses, were quick to support the position of business leaders.

The CEO of the German chemicals giant BASF, Martin Brudermüller, became a particularly vocal advocate of the dependency camp, predicting that a cutoff from Russian gas "could bring the German economy into its worst crisis since the end of World War II and destroy our prosperity" and asking, "Do we knowingly want to destroy our entire economy?" (Brankovic and Theurer 2022, par. 4 and 12).

Yet in some cases, the very same businesses whose CEOs had denied any short-run possibility of gas savings or substitution announced substantial reductions in gas usage only a few weeks later or found substitution possibilities of the very kind that had been discussed in the public debate.

For instance, having warned of a shutdown of its huge plant in Ludwigshafen, BASF announced soon thereafter that its Verbund system would be able to run with half the usual gas supplies and that gas-intensive ammonia production could be transferred to a BASF plant in the United States and imported from there.[56]

To what extent these early statements shaped Germany's initial hesitancy to supply Ukraine with more advanced weapons quickly is a question that future historians will have to address. But it is worth highlighting that neither economic arguments on demand responses to price increases and substitution possibilities, nor empirical studies from previous interruptions of energy supplies in other countries, carried enough weight to be a counterweight to the presumed real-world knowledge of business leaders, as conflicted as they might have been. Both theoretical and empirical reasoning of economists was deemed much less relevant than the judgment of company CEOs, a major reason likely being the potential political costs of going against the explicit advice of company and union leaders.[57]

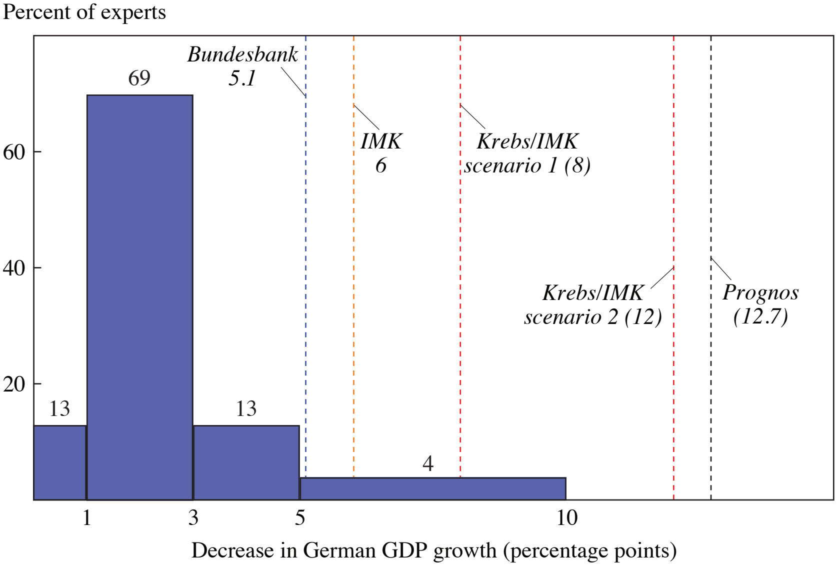
A second important lesson relates to the strategic use of think tanks associated with business and union interests to increase the uncertainty of cost estimates.[58] In practice, individual industry and union lobbies would pay for additional studies that arrived at high-cost estimates using extreme assumptions. Figure 13 contrasts the prediction of some of these studies to an April 2022 survey of academic economists about the likely effects of a Russian gas cutoff. Although the bulk of responses of academic economists were clustered in a reasonably narrow range up to 5 percent of GDP,

56. While BASF had been publicly stating that half of its normal gas supplies would be sufficient as early as March 2022, one particularly clear version is an investor conference call presentation from July 2022 stating, "Continued operation at Ludwigshafen site is ensured down to 50 percent of BASF's maximum natural gas demand" (BASF 2022; and case 18 in online appendix E). For ammonia substitution via imports, see section III.B and cases 2 and 15 in online appendix E.

57. After criticizing the "irresponsible use of mathematical models" on the *Anne Will* TV show (see introduction), Chancellor Scholz added, "I don't know absolutely anyone in business who doesn't know for sure that [entire branches of industry shutting down in the event of a gas cutoff] would be the consequences"; see the transcript and English translation available at https://benjaminmoll.com/Scholz/.

58. Banerjee and Duflo (2019) warn against the role of economists representing special interests in the public debate. Two special interest–financed think tanks stand out in Germany: the Institut der deutschen Wirtschaft (IW), which is financed by various industrial lobbies, and the Institut für Makroökonomie und Konjunkturforschung (IMK), which is largely financed by the German trade union federation DGB.

Figure 13. Studies Financed by Special Interest Groups Predicted Much Larger GDP Losses than Academic Economists



Source: Centre for Macroeconomics (CFM).

Note: The histogram represents the answers by European academic economists to question 2 in the April 2022 CFM survey on the effects of an embargo on Russian gas, "By how much would an immediate EU-wide import ban on Russian gas reduce German GDP growth per annum in 2022-3, in percentage points (pp), if the government offset the costs with a well targeted fiscal policy?" The dashed lines plot the estimates by Deutsche Bundesbank (2022), Behringer and others (2022), Krebs (2022), and Prognos (2022). For context, IMK is a union-financed think tank, the Krebs study was paid for by the German trade union federation DGB, and the Prognos study was paid for by a business association.

the studies financed by special interest groups produced much larger numbers of up to 12.7 percent of lost output.[59]

While the economic debate focused on the content of these studies and the underlying extreme assumptions, their political goal was a different one. By substantially broadening the range of potential cost estimates of a cutoff from Russian gas, they undermined public confidence in the reliability of

59. Centre for Macroeconomics (CFM), "Effects of an Embargo on Russian Gas," The CFM Surveys, https://www.cfmsurvey.org/copy-of-survey-2022-05. For reference, figure 13 also plots the largest cost estimate not financed by a special interest group, a 5.1 percent GDP drop predicted by Deutsche Bundesbank (2022). It is worth pointing out that Bundesbank cost estimates significantly exceeded those of other comparable institutions. For example, three IMF studies—Lan, Sher, and Zhou (2022), Albrizio and others (2022), and Di Bella and others (2022)—predicted more moderate economic losses of up to 3 percent of GDP. Also see the follow-up study by Albrizio and others (2023).

any cost estimate and increased uncertainty about the consequences in the eyes of the public. The impression remained that even experts could not agree about this matter so the prudent thing was to conclude that we simply cannot know how bad things can possibly get—reinforcing the approach taken by policymakers. Given that the uncertainty about economic estimates was so large, they could be dismissed altogether and other sources of information—such as contacts with company leaders—could be considered reliable.

Ultimately, the main effect of these academically questionable studies that arrived at extremely high economic costs was to create the impression of uncertainty, allowing policymakers to dismiss academic advice as too uncertain. A good example of this is captured in the following quote by Jörg Kukies, the head of the Economics Division in the Chancellor's Office in Berlin: "We will never ever be able to determine whether this has a 2 percent or 10 percent GDP impact. . . . We are simply trying to take the pragmatic middle course because we do not know and cannot know [what the effect would be of] such an abrupt termination" (Kukies 2022, minute 8:55 and 10:13).[60]

VII. Conclusion

It was primarily the economy's ability to adapt in combination with the insurance offered by trade and (some) good economic policymaking that blunted Putin's energy weapon: as prices rose, German producers and households reduced demand and substituted away from natural gas, the country quickly sourced alternative gas supplies, and policymakers implemented well-designed policies to support households and firms that maintained price signals to encourage gas to go to the sectors and countries where it was most needed.

The cutoff from Russian gas is an unusually clear case of how consumers and producers react when an important input (here natural gas) becomes scarce and expensive. As new data covering the 2022–2023 time period are starting to become available, future work should examine in more detail how this significant shock propagated across sectors, regions, and countries as well as its distributional effects. This work could also use the gas cutoff

60. The original German is "Wir werden es nie und nimmer entscheiden können, ob das jetzt 2% oder 10% BIP-Einfluss hat. . . . Wir versuchen einfach den pragmatischen Mittelweg zu gehen, weil wir nicht wissen und nicht wissen können [was der Effekt ist] bei einem so abrupten Abbruch."

as a natural experiment to identify and estimate various elasticities that will be relevant in other contexts. Prime examples are questions regarding the green transition, in particular projecting the economic impact of rising carbon prices, which will affect similar sectors of the economy as the gas shock. There are, however, limits to the comparison. For example, decarbonization will imply a continuous and universal decrease in the supply of emission permits, while the gas crisis cut out only one major gas supplier (Russia).

The main rationale for sanctioning Russian energy exports has always been simple, namely, that these exports represent an important source of fiscal revenues for the Russian state—money that is then used to wage war in Ukraine. As Oleg Itskhoki has put it: "Each marginal euro received [by Russia] from energy exports to Europe contributes exactly one euro to the war, as simple as that."[61]

Despite this clear rationale for sanctioning Russian energy exports, Western countries opted for a cautious approach and such sanctions did not begin in earnest until the EU crude oil embargo took effect in December 2022, almost ten months after the start of the war. Sanctions on gas exports have still, to this day, been absent from any sanctions packages. This delayed and cautious implementation of energy sanctions contributed to Russia earning record export revenues in 2022 and likely to its ability to wage war in Ukraine. For example, Babina and others (2023) argue that even though the EU oil embargo only came into effect in December 2022, it has already materially affected Russian export revenues and, furthermore, that an earlier introduction of the EU oil embargo and the G7 price cap in the immediate aftermath of the invasion could have reduced Russia's oil export earnings by up to $50 billion or about one-third.

Naturally, just like Germany substituted and adapted in the face of the gas cutoff, Russia has also been substituting and adapting in the face of Western sanctions. The power of substitution cuts both ways. However, the Russian government's strong reliance on fiscal revenues from energy

61. X (Twitter), April 8, 2022, https://twitter.com/itskhoki/status/1512508687641763844?s=20. A particularly good exposition of the case for energy sanctions is by Guriev and Itskhoki (2022). Opponents of the energy embargo idea have often argued that Russian war expenditures would be unaffected because the Russian government can print its own money and therefore does not need to rely on export revenues. A good rebuttal of this argument is made by Hanno Lustig: "Suppose we did a helicopter drop of dollars in Red Square in Moscow. If no one bothers to pick them up, then export curbs are indeed irrelevant. Not a likely outcome of this experiment"; X (Twitter), June 4, 2022, https://twitter.com/HannoLustig/status/1533000546659012608?s=20.

exports does mean that the situation is asymmetric and that export sanctions likely bite.[62]

One manifestation of declining export revenues due to energy sanctions has been the ruble's depreciation throughout the spring and summer of 2023 (Itskhoki and Mukhin 2022; Lorenzoni and Werning 2023). This has already forced hard choices on Russian policymakers with the central bank recently implementing significant interest rate hikes (Guriev 2023).

Keeping Russia's natural gas exports out of the sanctions regime generates substantial revenues for the Russian state—some €200 million per week (Levi 2023). Not sanctioning the financial institutions used for the corresponding payments, specifically Gazprombank, is similarly problematic. Apart from the unsanctioned gas exports contributing to Russia's war effort, Europe effectively allowed Russia to decide on the price and volume of these exports to individual destination countries, thereby creating divisions between countries that still receive Russian gas via pipeline (e.g., Austria and Hungary) or LNG (e.g., Spain) and those that do not. As Europe will continue to use natural gas for at least two decades and Russia's gas export infrastructure to Europe is still very potent, Europe should consider taking advantage of the historically low flows to establish joint political control over gas flows from Russia rather than buying cheaply produced gas at high prices.

The failure by Western countries to implement sanctions sooner and more decisively represents a major missed opportunity to stand up to Putin and help avert enormous human suffering in Ukraine. There are good arguments that the West should tighten its sanctions regime against Russia, including on natural gas and oil, and avoid making the same mistakes in future similar crises.

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62. In the words of former US senator John McCain: "Russia is a gas station masquerading as a country. It's kleptocracy. It's corruption. It's a nation that's really only dependent upon oil and gas for their economy, and so economic sanctions are important." Transcript of McCain's interview on CNN's *State of the Union with Candy Crowley* is available at https://cnnpressroom.blogs.cnn.com/2014/03/16/sen-john-mccain-u-s-needs-fundamental-reassessment-of-russia-relationship/.

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Comments and Discussion

COMMENT BY

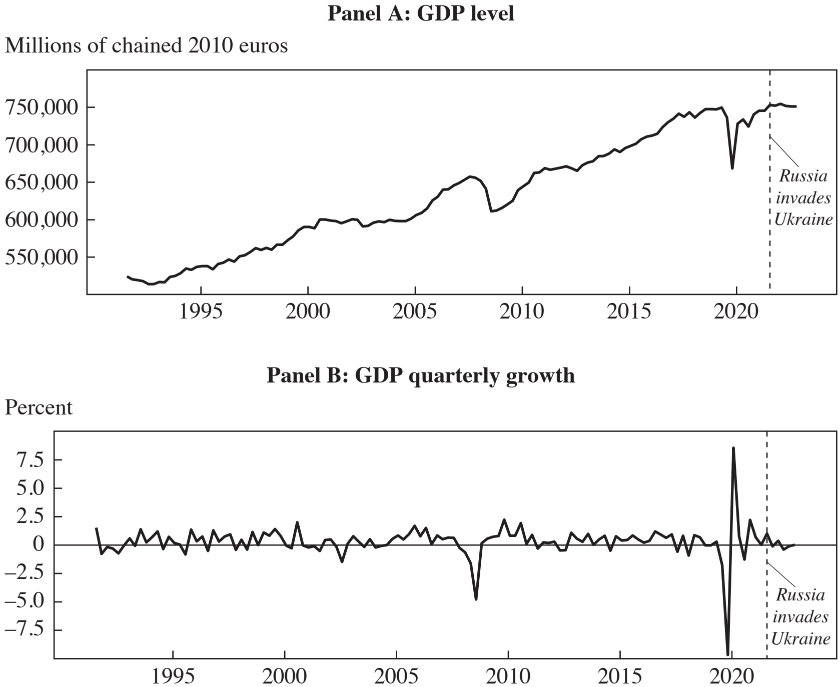
JAMES D. HAMILTON[1] Moll, Schularick, Zachmann, and their colleagues staked out a bold position in March 2022, predicting that loss of Russian natural gas would cause substantial but manageable challenges for the German economy (Bachmann and others 2022). They took a lot of flak for that conclusion from analysts who thought the economic consequences would be much more dire. But the subsequent events proved their prediction to have been largely correct. It's very appropriate at this point to provide a retrospective on how events unfolded a year and a half after Russia invaded Ukraine. I see my role as a discussant to be to highlight a number of the points made by Moll, Schularick, and Zachmann, perhaps with a slightly different emphasis from theirs.

ALL IS NOT WELL IN GERMANY The first point that bears repeating is that the German economy is currently struggling. Some in the financial press have started again referring to Germany as the "sick man of Europe" (*Economist* 2023). Panel A of figure 1 plots the level of German real GDP. Apart from the sharp drop and rebound associated with the COVID-19 pandemic, German output has essentially stagnated since 2019 and fell on average since the invasion.

Other measures corroborate that assessment. Panel A of figure 2 plots the Bundesbank's weekly index of the German real economic activity. This characterizes the German economy over the last year as experiencing a modest but clear decline. Panel B plots the ifo sentiment index based on a survey of German firms. Undeniably, many people in Germany have been very pessimistic about the economy since the invasion.

1. I thank Christiane Baumeister for assistance with obtaining the data for this discussion.

Figure 1. Level and Quarterly Growth Rate of German Real GDP

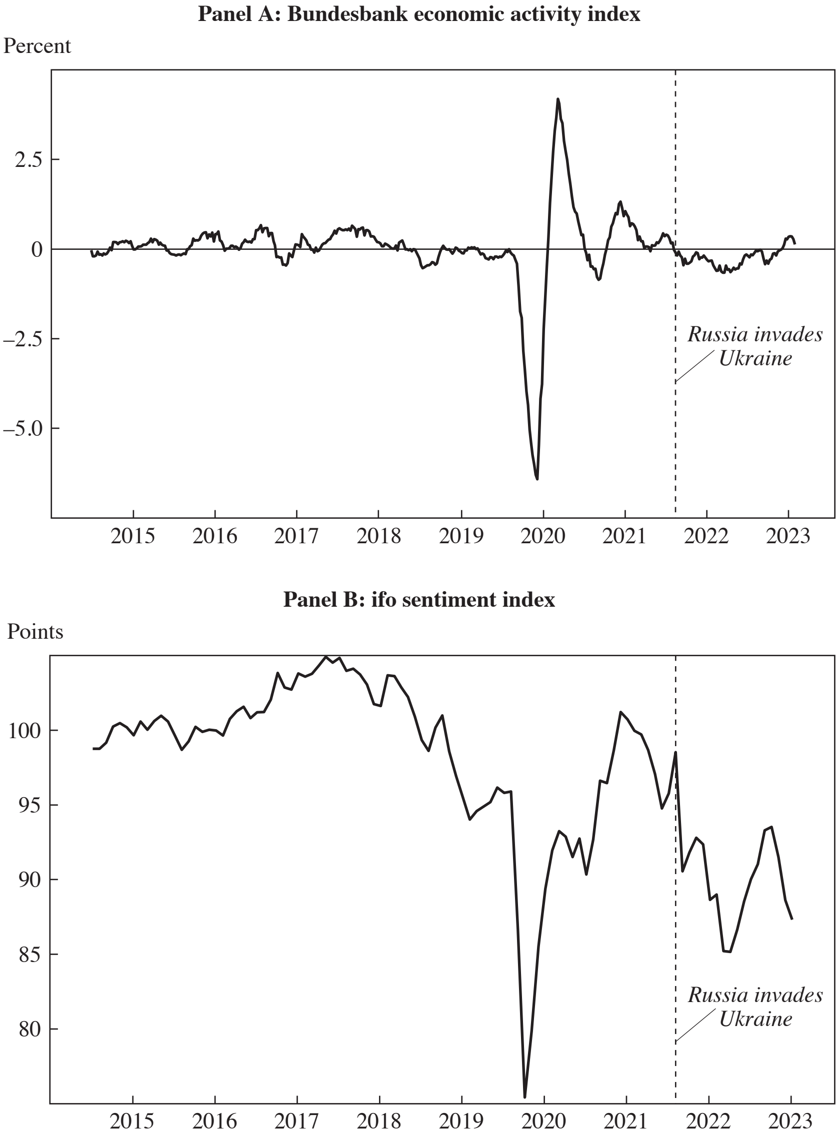


Source: Eurostat, series CLVMNACSCAB1GQDE, retrieved from FRED.
Note: Data are quarterly from 1992:Q2 to 2023:Q2.

To be sure, the challenges for the German economy began well before Russia invaded Ukraine. And the magnitude of the drop in output in 2022 is a far cry from the dire warnings of some prognosticators, and quite consistent with Bachmann and others (2022)'s original assessment of a substantial but manageable downturn. Still, I think we can agree that the German economy has faced some significant headwinds, and that disruptions in the supply of energy were part of those headwinds.

WHAT BROUGHT DEMAND DOWN? Figure 3 plots the wholesale price of natural gas in Germany. This exhibited a significant spike before the invasion, which Moll, Schularick, and Zachmann document was a result of prewar supply manipulations by Russia. The price went up spectacularly following the invasion. But natural gas prices began to fall dramatically after the summer of 2022 and are currently well below the levels even of 2021. Not only was the effect of the natural gas supply disruptions on German real

Figure 2. Other Measures of German Real Economic Activity



Source: Weekly Activity Index, Deutsche Bundesbank; and Business Climate Index for Germany, ifo Institute.

Note: Panel A data are weekly from January 5, 2015 to August 7, 2023. Panel B data are monthly from 2015:M1 to 2023:M7.

Figure 3. Wholesale Natural Gas Price in Germany

Source: Deutsche Börse Group.
Note: Wholesale price of natural gas in Germany, daily from January 2, 2013 to July 28, 2023.

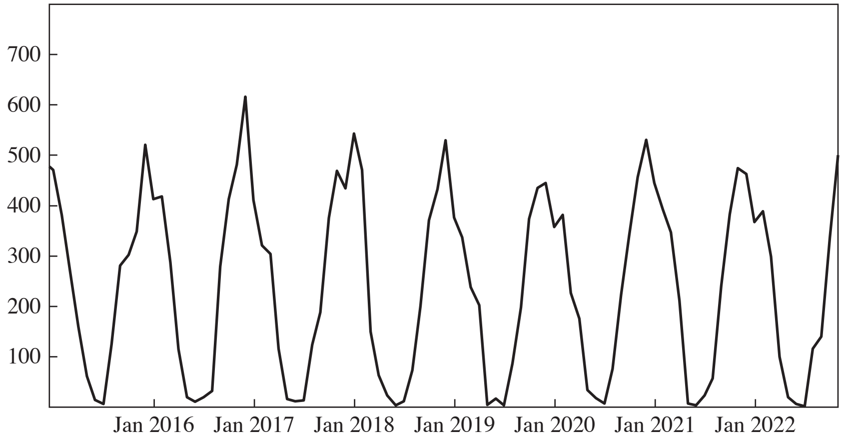
output more modest than many people had anticipated, so was the effect on the price of natural gas itself. One has to suspect that these two developments are related.

The first possibility many of us would consider is that there was some other factor shocking the demand, such as a milder than usual winter in 2023. But there's no real evidence that weather is the explanation (figure 4). The authors carefully investigate the contributions of weather to demand and conclude, correctly in my opinion, that weather is not the explanation for the mildness of the economic effects.

But why did the quantity demanded fall so much if the price actually fell? Part of the answer is the administered nature of the price paid by final users. This rose more slowly than the wholesale price, and the subsequent wholesale price declines were not immediately passed on to residential and business customers (Ruhnau and others 2023, fig. 1).

Another possible shift in the demand curve could arise from voluntary conservation efforts. The authors discount the importance of these, noting that the federal gas-saving campaign had a very limited budget. I would push back a little at the proposition that people only change their behavior if the government tells them to. I suspect that many German businesses and consumers felt a civic duty to conserve wherever they could. When the tanks

Figure 4. Heating Degree Days in Germany



Source: Eurostat (data code nrg_chddr2_a).
Note: Heating degree days in Germany, monthly from 2015:M1 to 2022:M11.

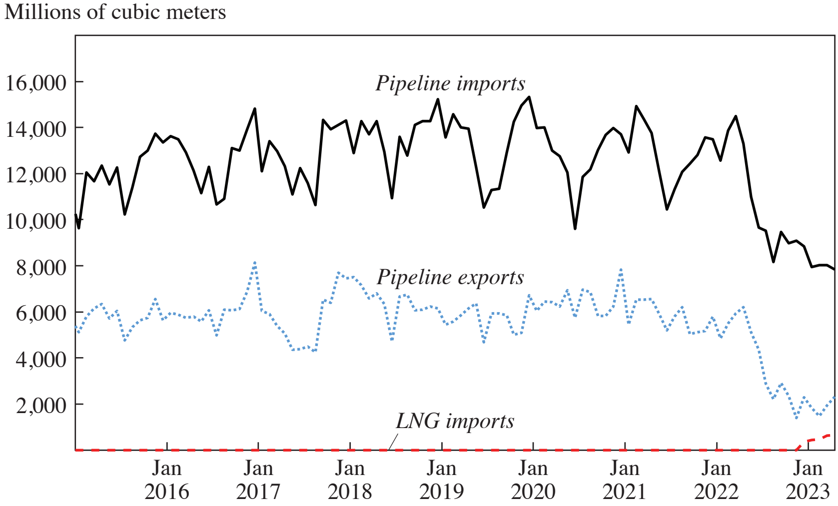
are rolling into formerly peaceful villages, that may motivate some people to act in a way that government-sponsored advertising and slogans could not. I suspect that voluntary conservation may have played a role both in mitigating the price effects and, as I will elaborate below, in mitigating the real output effects as well.

Figure 5 highlights what I see as the single most important reason why reduced natural gas imports were less disruptive to the German economy than some had feared. The authors invested considerable effort into tracking flows of natural gas into and out of Germany. I have done something much simpler based on the gross flows reported in the Joint Organisations Data Initiative (JODI) database.[2] The top line in panel A shows that the monthly pipeline imports of natural gas into Germany fell by about 6 billion cubic meters, equivalent to 63 TWh per month and more than a 40 percent drop from preinvasion levels. Part of the initial worry came from people wondering: how in the world could Germany cut its use of natural gas by that much? The answer is, it didn't. As seen in the middle line in panel A of figure 5, most of the adjustment came in the form of reduced exports of natural gas from Germany. The loss of German net imports (panel B) is much more modest, around 2 billion cubic meters or

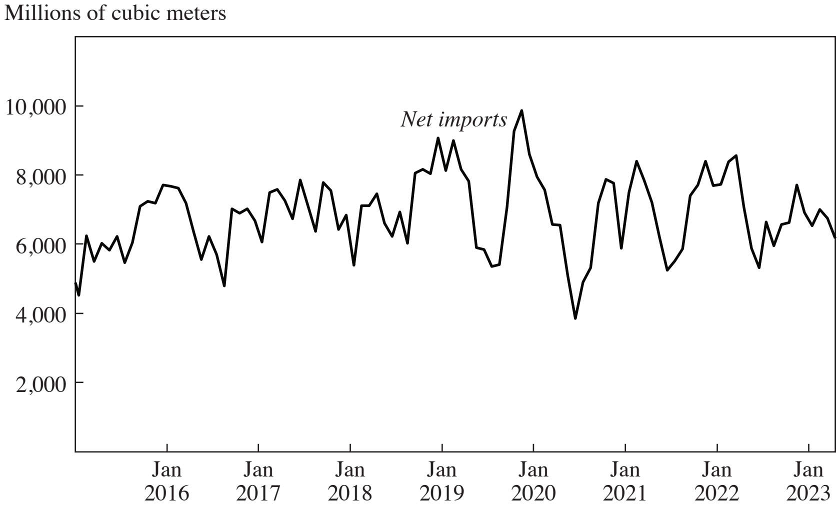
2. JodiGas, "The JODI Gas World Database," https://www.jodidata.org/gas/.

Figure 5. German Natural Gas Imports, Exports, and Net Imports

Panel A: German natural gas imports and exports



Panel B: German natural gas net imports



Source: JODI Gas World Database.

Note: Panel A presents data on German pipeline imports, LNG imports, and pipeline exports of natural gas. Data are monthly from January 2015 to May 2023. Panel B reflects total imports minus total exports.

21 TWh per month. This quick estimate is consistent with the cumulative decline in German consumption of 157 TWh that the authors arrived at in table 2 in the paper, using much more careful methods.

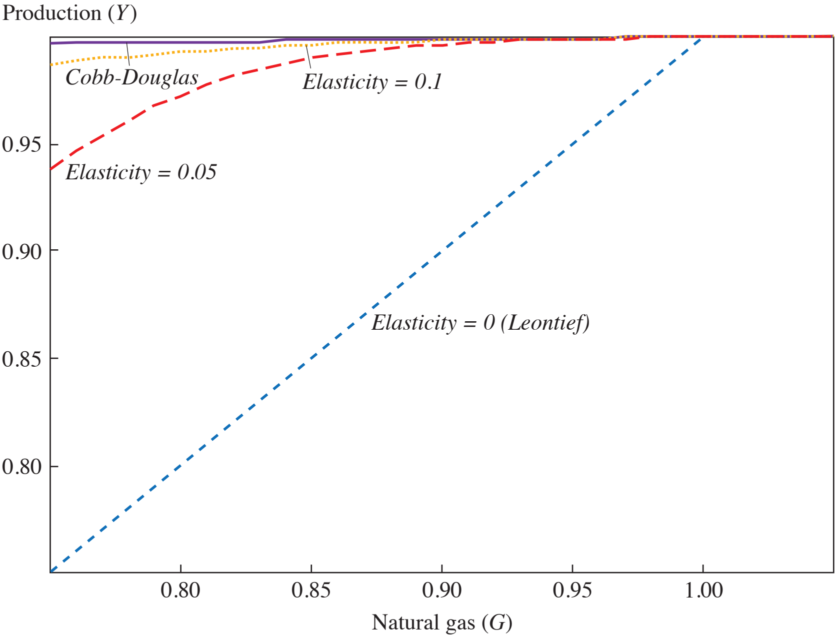
My conclusion is that the single biggest reason that the disruptions were less damaging to the German economy than some had feared is that Germany did not have to make the adjustments by itself. I see this very much as an illustration of the main point that the authors are making about the power of substitution. Markets find ways to adapt to challenges that policymakers and individual business planners can easily overlook. Their paper provides a wonderful demonstration of how this theme plays out in so many different ways.

DISCUSSION OF THE EFFECTS ON REAL GDP Let me now turn to the central question of the effects on overall real economic activity. Moll, Schularick, and Zachmann provide a simple illustration of the economy's ability to adapt using an aggregate CES production function:

$$Y = \left\{ \alpha^{1/\sigma} G^{(\sigma-1)/\sigma} + (1-\alpha)^{1/\sigma} \left[F(K, N) \right]^{(\sigma-1)/\sigma} \right\}^{\sigma/(\sigma-1)}.$$

Here Y is total real output, and G, K, and N are utilization of natural gas, capital, and labor, respectively, while σ is the elasticity of substitution and α determines the euro value of natural gas expenditures as a share of total nominal output. I take the initial expenditure share to be 1 percent for the calculations below. This corresponds to the authors' equation (1), where the only change I have made is to spell out explicitly the factors labeled as other inputs X in the authors' formulation. The question they ask is: what would happen to total output if utilization of natural gas were to change with utilization of capital and labor constant? The answer is plotted in figure 6, which reproduces the authors' figure 3. The graph shows how much Y would go down according to the above equation if natural gas consumption was cut by up to 25 percent while K and N did not change. If there is zero elasticity of substitution (corresponding to a Leontief production function), output would fall by the amount that natural gas was reduced. The authors' point is that the substitution elasticity can be very small, but as long as it is nonzero, effects are much more modest than would be predicted in the extreme Leontief case. For example, if $\sigma = 0.05$, output would only fall by 6 percent when consumption of natural gas is reduced by 25 percent. The authors' actual quantitative analysis is based on a detailed model of industry interactions

Figure 6. Effects of Changing Utilization of Natural Gas When Utilization of Capital and Labor Are Unchanged for Different Elasticities of Substitution



Source: Reproduced from figure 3 in the paper.
Note: Horizontal axis shows utilization of natural gas as a fraction of original level. Vertical axis shows total production as a fraction of original level.

as in Baqaee and Farhi (2019). But the simple summary in equation (1) gives some insight into what lies behind these calculations.

I have reproduced here the calculation in their figure 3 in order to highlight the implicit assumption that the drop in natural gas consumption does not lead to any change in utilization of capital or labor. I would argue that the defining characteristic of an economic recession is a dramatic decline in the utilization of capital and labor. From this perspective, one might say that analysis like that in their figure 3 rules out the possibility of an economic recession by assumption.

Is there a reason to think that a disruption in energy supplies could result in underemployed labor and capital? I've argued that, historically, underemployed labor and capital were very important in understanding why some historical oil price shocks were followed by economic recessions in the United States. We often observe in those episodes that the oil price increases were followed by substantial declines in spending on new cars and other items. Quantitatively, the decline in car production made a significant contribution to the total observed decline in GDP in these historical downturns (Hamilton 2009). One can make a case that this correlation is causal. For example, the decline is the biggest for the least fuel-efficient vehicles, with production of more fuel-efficient cars sometimes even rising.

The original analysis by Bachmann and others (2022) recognized the potential importance of this issue. But they argued that it need not overturn their analysis, to the extent that "fiscal and monetary policies cushion potential demand-side Keynesian effects" (Bachmann and others 2022, 3). As long as we are taking this opportunity to praise the many ways in which their original analysis got so many things right, we should perhaps acknowledge that this particular policy prescription was not among them. I think we would all agree today that more fiscal and monetary stimulus was not an option for Europe in 2022. Indeed, the consensus view of many today is that excessive stimulus in 2021–2022 in Europe, the United States, and much of the rest of the world was a key factor in the resurgence of inflation. I would further argue that additional stimulus was also not an option in responding to the oil shocks of 1974 or 1979, for the same reason.

The authors were correct that mainstream macroeconomic models assume that demand effects could be mitigated using appropriate Keynesian-type stimulus. But that is not my view. I maintain that recessions do not result from a mismatch between aggregate demand and an aggregate production function, but instead from a mismatch between the composition of demand and the specific goods to which specialized resources are dedicated in advance to produce. Workers and factories may be capable of producing a huge number of gas-guzzling sports utility vehicles. But if people no longer want to buy those, the result is inevitably going to be underutilized capital and labor, for which added monetary stimulus is not the solution. I show how demand spillovers operating through these factors can play out in a dynamic general-equilibrium setting in Hamilton (2023).

In the present paper, Moll, Schularick, and Zachmann investigate possible demand spillovers in more detail than in the original study. They conclude that in the case of Germany in 2022, the observed magnitude of demand spillovers was limited. I agree with their analysis, and I think it is related to the authors' broader theme of the power of substitution. When gasoline prices double, the short-run options for most consumers are limited. They go ahead and fill up the gas tank, whatever it costs, and cut spending someplace else. In my view, it was those other cuts in spending that were the main cause of the economic disruption associated with historical oil price shocks. The authors do a wonderful job of documenting the rich variety of ways that firms can (and did) reduce their use of natural gas without significant disruptions in other spending. And individual consumers can (and did) reduce their use of natural gas by lowering the thermostat, perhaps spurred in part by civic conscientiousness, and again without disrupting other economic spending. I believe that the authors are also correct that another reason why natural gas disruptions may be less disruptive than some historical oil shocks is the fact that the expenditure share of natural gas is on the order of 1 percent, in contrast with a number like 4 percent for the economic value of refined petroleum products. In my opinion, these were the primary reasons why the significant disruptions in GDP that some analysts had feared never came to pass.

SUMMARY There is much to like about this paper. I hope it will end up becoming a classic case study in the theme posed by the paper's title—the power of substitution.

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COMMENT BY

TAREK A. HASSAN The paper studies the adjustment of the German economy after Russia cut Germany off from gas supplies in the summer of 2022. The authors highlight three main findings. First, despite Germany's notable dependence on Russian gas, the gas cutoff proved to be a manageable shock for German firms. Second, the impact of the shock was transient, and its effects were primarily concentrated within a handful of sectors heavily reliant on gas. Third, German firms effectively employed two primary strategies for adjustment: reducing gas consumption and seeking alternative gas suppliers. Combined with good policy, these measures were sufficient to prevent a recession following the gas cutoff.

The insights presented in this paper and its precursors (Bachmann and others 2022a and 2022b) are invaluable, providing both academic and practical contributions. The authors illuminated the implications of canonical economic theory and distilled them into actionable policy recommendations at a time when such guidance was urgently needed.

Before turning to my main comment, I would like to reiterate two important points. First, sound economic policy was pivotal in the relatively benign outcome of the gas crisis. The German government found creative ways to make transfers to gas consumers that preserved price signals and incentivized them to reduce gas consumption. These schemes allowed the economy to adapt quickly and flexibly. In a similar vein, it is important to recognize that predictions based on aggregate production functions, like the ones made in the present paper, hinge on the preservation of price signals and incentives. There were many examples of poor policy decisions during this period, such as price caps and rationing. They serve as stark reminders of how the situation could have deteriorated.

Second, interconnected European gas markets played a vital role in mitigating the impact of the crisis (Papież and others 2022). Investments made since 2015 to connect the German gas market with the rest of Europe proved to be prudent and averted a recession.

Having made these initial points, the majority of this comment will concentrate on the broader issue of assessing the economic impact of ongoing economic shocks. Policymakers are frequently confronted with the challenge of dealing with impending or unfolding shocks. The German gas crisis is just one example in a landscape that includes crises like the COVID-19 pandemic, Brexit, sovereign defaults, government shutdowns, wars, and the like. More often than not, these shocks must be assessed and reacted to long before concrete data become available.

Measuring exposure to such shocks can be a complex endeavor, often difficult to accomplish beforehand. The German gas crisis, in this respect, was a comparatively straightforward case, as historical data on sector-specific gas imports were readily available. However, for many other types of shocks, identifying the affected firms and sectors can be challenging, if not impossible.

Typically, the approach is to make predictions based on economic theory, make a call on who is likely to be affected, and then wait several months to validate these predictions with accounting data. This was precisely the process followed in the case of the present paper: the authors had to formulate predictions based on theory (Bachmann and others 2022b), offer policy recommendations (Bachmann and others 2022a), and subsequently wait nearly a year and a half to perform a postmortem analysis in the present paper.

In essence, we often find ourselves in the unenviable position of comprehending the economic consequences of shocks only after they have occurred, rendering proactive policymaking difficult.

In the sections below, I will argue that systematic analysis of corporate earnings calls can offer real-time, powerful insights for analyzing the economic impact of ongoing and anticipated shocks. By examining what executives communicate to their investors about the state of their firms and their expectations regarding the impact of a given crisis, we can expedite quantitative analysis, allowing for more timely reactions and sound policy advice. I will argue that text-based data from earnings calls therefore hold substantial value for macroeconomic analysis.

The following sections of this comment will revisit the main steps of the authors' analysis, relying exclusively on the data generated from earnings calls available in 2022. Through this approach, I aim to demonstrate that analyzing these earnings calls could have led to similar conclusions in near real time, eliminating the need to wait for accounting data to become available and providing an opportunity for proactive and effective policymaking.

MEASURING EXPOSURE TO THE GAS SHOCK Executives at thousands of listed firms in eighty-two countries hold quarterly English-language calls with their analysts and investors to discuss any major issues confronting their firms. These high-stakes conversations typically begin with a management presentation, followed by a Q&A session where executives respond to analysts' questions. Transcripts of these earnings calls are widely available. I source them from London Stock Exchange Group and analyze them using NL Analytics.

The approach developed in Hassan and others (2019, 2023a, 2023b) measures the exposure, risk, and sentiment firms associate with a given shock—in this case, the cutoff from Russian gas—by analyzing what call participants say about the shock on their firm's quarterly earnings call.

What do German firms say about how a potential Russian gas shutoff will affect them?

The first step of the analysis is to generate a set of keywords associated with discussion of gas supply. For example, we may start with *gas supply*, *gas availability*, *gas shortage*, *gas pipeline*, *Nord Stream*, and so on. There are very good methods for doing this in a systematic way. Here, I follow the approach in Bloom and others (2021), where I use an embedding vector model trained on earnings calls like a custom-trained thesaurus to give suggestions for different phrases executives might use when discussing reliance on Russian gas. For each suggestion, I then read ten randomly sampled excerpts of text where the phrase is mentioned in earnings calls to minimize false positives.[1]

We then use these keywords to find the sentences where call participants talk about gas supply. A simple measure of the extent to which a given firm expects to be affected by a possible gas shutoff is then simply to measure the number of sentences call participants devote to the subject in that firm's earnings call in that quarter:

$$(1) \qquad GasExposure_{i,t} = \#\text{ Sentences that mention gas.}$$

The intuition is simply that managers and analysts devote more time to events of greater importance to the firm.

Second, to measure the amount of risk call participants associate with the shock, we count which of the sentences identified in equation (1) also mention *risk*, *uncertainty*, or any synonym thereof (Hassan and others 2019).[2]

$$(2) \qquad GasRisk_{i,t} = \#\text{ Sentences that mention gas and risk synonym.}$$

We may think of *GasRisk* as the second-moment impact of the shock—a measure of how much uncertainty it generates for the firm. Finally, to distinguish first-moment impacts (bad news) from the shock's effect on risk, it is sometimes useful to measure the sentiment with which call participants discuss the shock

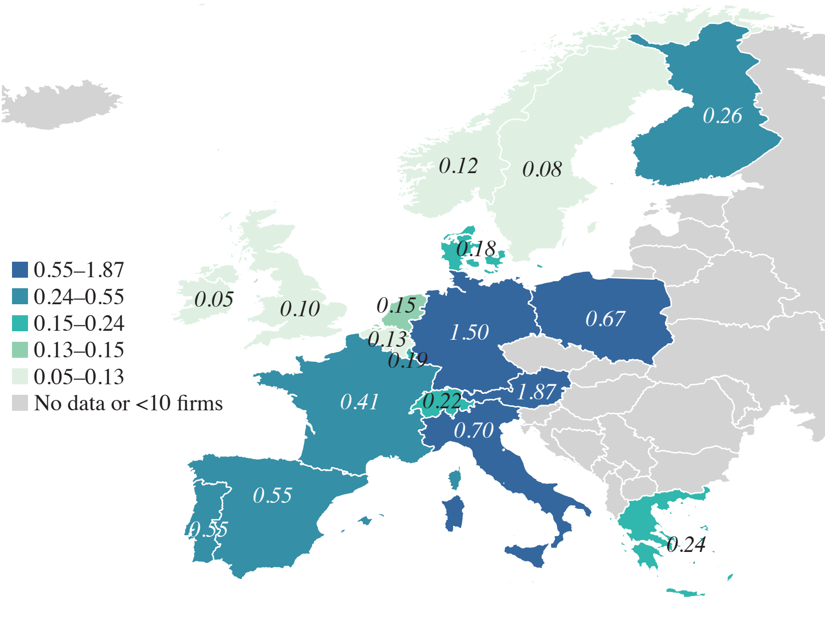
$$(3) \qquad GasSentiment_{i,t} = \#\text{ Positive} - \#\text{ Negative sentences that mention gas.}$$

Loughran and McDonald (2011) provide a widely used library of tone words to make this distinction.

1. For methods that do not require human intervention, see Hassan and others (2019) and Sautner and others (2023).

2. Single-word synonyms of *risk*, *risky*, *uncertain*, and *uncertainty* as given in the *Oxford Dictionary* (excluding *question* and *questions*).

Figure 1. Natural Gas Exposure in European Countries, 2022:Q3



Source: NL Analytics.

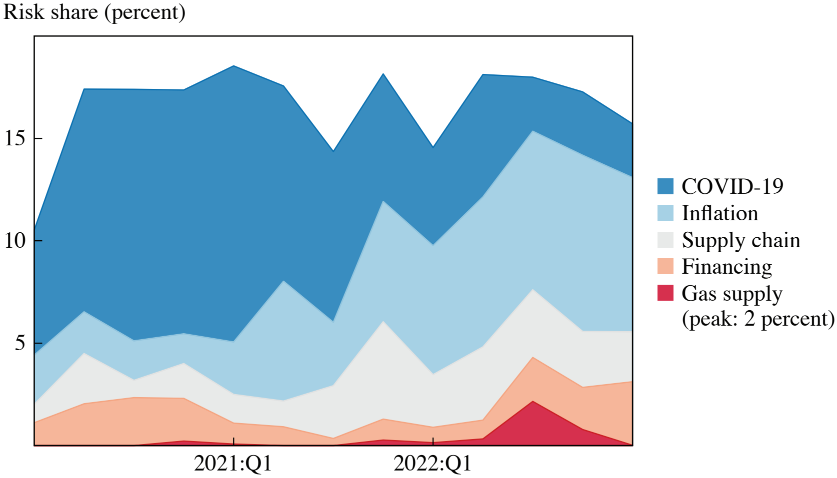
Note: This figure illustrates the spatial distribution of natural gas exposure across European countries. The numbers provided represent the average count of sentences that mention natural gas supply in all earnings calls held by firms headquartered in each respective country during the third quarter of 2022. Countries with fewer than ten transcripts in that quarter are excluded.

One useful feature of these data is that they are at the firm-quarter level, which can then be merged with conventional firm-level data from Compustat Global and other sources.

The third step is then to analyze the data. Importantly, because each of these series is generated from text, we can also use them to identify the most important pieces of text to read to understand the country-, firm-, and sector-level variation in our measures of gas exposure, risk, and sentiment. I will show one example of such targeted reading below.

Figure 1 shows the variation in *GasExposure* across European firms in the third quarter of 2022. Notably, it illustrates that German and Austrian firms exhibited the highest degree of exposure, dedicating a substantial portion of their discussions to this issue (mentioning the possibility of a Russian gas shutoff 1.87 and 1.5 times on average in their earnings calls).

Figure 2. Decomposition of Risks Discussed by German Companies, 2020:Q1–2023:Q1



Source: NL Analytics.

Note: The figure illustrates the proportion of risk mentions among 190 German firms related to gas supply in comparison to four other topics: COVID-19, inflation, supply chain disruptions, and financing challenges. The fraction for each topic is calculated by dividing the number of sentences that mention risks associated with that topic by the total number of sentences that reference risk in general.

Additionally, a striking geographic pattern emerges, as the countries with a relatively larger number of mentions cluster closely together. This spatial correlation underscores the regional nature of the impact, indicating a shared concern among Central and Eastern European nations about the possible gas cutoff.

GAS EXPOSURE VERSUS OTHER RISKS FACED BY GERMAN FIRMS Although it is clear that German firms were more concerned about gas supply than firms in many other European countries, it is important to know how the threat of a gas shutoff compares with other prevailing concerns at the time.

A useful way of making such a cardinal comparison between different types of risks is by considering what share of mentions of risks is attributable to gas supply relative to other topics. An average earnings call transcript tends to contain about six sentences that mention risk, uncertainty, or a synonym thereof. Figure 2 shows the composition of risk discussions among the 190 German firms in our sample. It shows what fraction of risk mentions corresponds to gas supply and each of four other topics: COVID-19, inflation, supply chain disruptions, and financing challenges.

In the early part of the sample, there was a pronounced anxiety tied to COVID-19, but by 2022:Q3, these fears had markedly diminished. The graph underscores that inflation-related risks have overshadowed other concerns since early 2022, emerging as the predominant risk for German firms (7.7 percent of all mentions of risk in the third quarter of 2022). Concurrently, worries related to the supply chain have also risen to prominence (3.3 percent). Notably, concerns related to both financing and the Russian gas supply stand at a relatively low 2.1 percent and 2.2 percent, respectively.

In other words, even at the height of the Russian gas crisis, concerns about gas supply are on par with or even secondary to a range of other concerns faced by the average German listed firm. Second, while concerns about inflation, supply chain, and COVID-19 are highly persistent, the anxiety around the gas supply sees a brief spike and then rapidly dissipates, contrasting sharply with the enduring concerns tied to other risk domains.

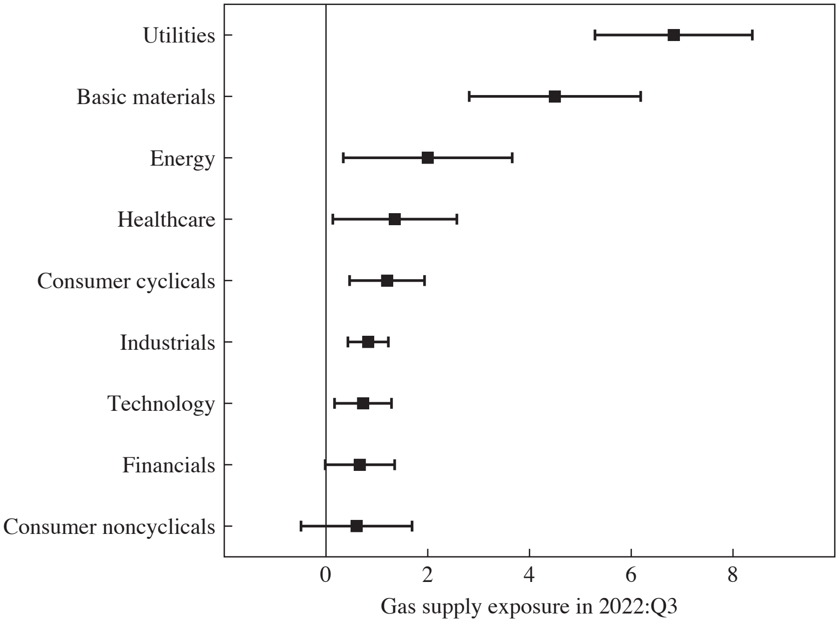
SECTOR-LEVEL IMPACT Although the Russian gas crisis was not the most urgent concern for the average German firm, it was a major source of concern for some firms in specific sectors. These, no doubt, were also highly vocal in the public discourse on the subject.

Figure 3 shows the average number of mentions of the Russian gas crisis across sectors. Evidently, the impact is highly concentrated. German utility companies, in particular, devoted significant attention to this issue, underlining its critical importance for them. Similarly, firms within the basic materials sector, which includes notable entities like BASF, exhibited significant conversations on the subject. Conversely, the remaining sectors exhibit much lower exposure. Consumer noncyclicals, for instance, only registered an average of 0.2 mentions of gas supply during the same period. Again, this evidence is consistent with the authors' assertion that a cascading failure of the German economy was never in the cards.

ADJUSTMENT TO THE SHOCK In a final step, I delve deeper into the authors' examination of how German firms adjusted to the challenges posed by the gas crisis. To accomplish this, I undertake a targeted reading of executives' statements regarding their plans. To this end, I download the text encompassing all 330 mentions of natural gas supply made by German firms from June 1, 2022, to December 31, 2022. Within this corpus, 157 sentences discuss specific strategies for addressing the crisis.

A rough reading of these text snippets reveals four primary categories of adjustment strategies embraced by German firms: a transition toward alternative energy sources, reductions in gas consumption, a shift toward

Figure 3. Average Mentions of Russian Gas Crisis across Sectors, 2022:Q3



Source: NL Analytics.
Note: This figure illustrates the average natural gas exposure of German firms across sectors in 2022:Q3. The exposure for each sector is determined by averaging mentions of natural gas supply across its firms for the quarter. Whiskers indicate 95 percent confidence intervals.

alternative suppliers of natural gas, and a reliance on government assistance. Table 1 gives examples of executives' statements in each category.

Figure 4 depicts the proportion of text excerpts referencing each of the four mitigation strategies. Switching to alternative fuels, such as oil or electricity, accounts for 30 percent of the mentions. Measures centered around curbing gas consumption comprise 25 percent; 23 percent discuss the identification of alternative gas suppliers, while 8 percent mention strategies that hinge on obtaining government assistance.

Interestingly, despite stemming from distinct data sources, these observations align seamlessly with the authors' conclusions. Both sets of findings underscore the significance of demand reduction and the pursuit of alternative gas sources as primary mechanisms that curtailed a larger impact of the gas crisis on the German economy.

STATEMENTS IN EARNINGS CALLS VERSUS THE MEDIA Before concluding, it is worth highlighting the differing communication styles executives choose

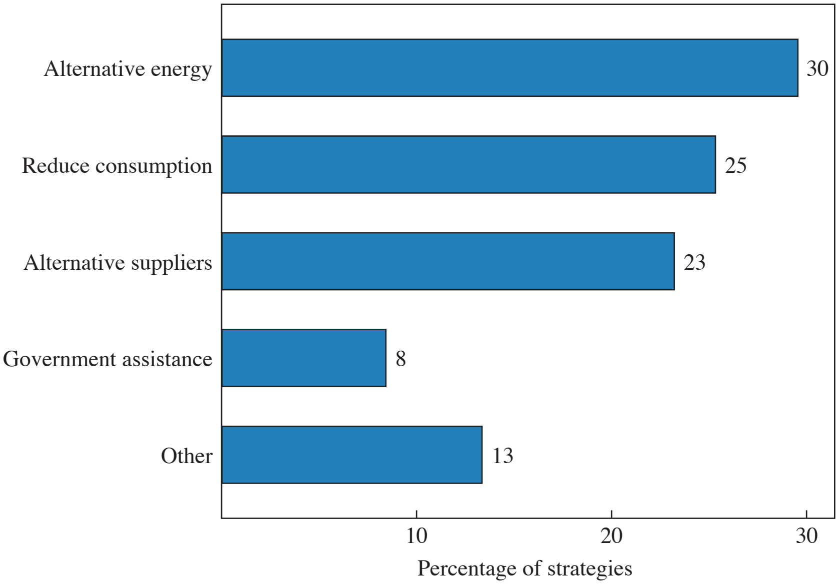
Table 1. Firm Strategies for Adjusting to Gas Cutoff

Strategies	*Transcript excerpts*
Alternative energy	"We can generate steam which we need for our production with fuel oil, electricity instead of natural gas." (Aurubis AG, Mineral Resources, August 5, 2022)
	"If needed, we are able to switch the heating supply and that's mainly for the painting from gas to heating oil in the short term and that's 100 percent." (Deutz AG, Industrial Goods, August 11, 2022)
Reduced consumption	"We prepared ourselves since the beginning of the war on the Ukraine to reduce our gas consumption as best as possible." (Infineon Technologies AG, Technology Equipment, August 3, 2022)
	"But overall, this is an expression of the fact that we've actually consumed significantly less gas. And if your question is how much less is in the order of magnitude of almost 40 percent lower gas consumption in Q3 than in the prior year quarter." (BASF SE, Chemicals, October 26, 2022)
Alternative suppliers	"We are also helping to diversify gas supply in Europe through investments in LNG infrastructure and LNG imports." (RWE AG, Utilities, August 11, 2022)
	"The further diversification of our gas procurement is well on track." (EnBW Energie Baden Wuerttemberg AG, Utilities, August 12, 2022)
Government assistance	"Since the beginning of the war, there have been regular meetings between German industry and the German government to look at scenarios for gas and other things." (Mercedes Benz Group AG, Automobiles & Auto Parts, July 27, 2022)
	"We are aware of and accept our responsibility for the health of millions of people. As such, we are confident in being granted priority access to gas supplies in the event of restrictions." (Gerresheimer AG, Healthcare Services & Equipment, July 13, 2022)
Other	"We have already significantly reduced our exposure in Germany by implementing preemptive measures. These include rearranging gas consumption between sites." (Beiersdorf AG, Personal & Household Products & Services, August 4, 2022)

Source: London Stock Exchange Group.

when addressing the public versus their investors. Those individuals who might have been motivated to amplify the projected effects of the Russian gas cutoff on their businesses in public media statements often conveyed a more balanced perspective during their earnings calls. For instance, Martin Brudermüller, the leader of BASF, mentioned in a newspaper interview dated March 31, 2022, that the cessation of Russian gas "could bring the German economy into its worst crisis since the end of World War II and destroy our prosperity" (Brankovic and Theurer 2022). Yet, in the earnings call on April 29, he detailed BASF's strategic response to reduced gas consumption, stating: ". . . [W]e have increased and will further increase our sales prices to pass on higher natural gas prices. At our European sites,

Figure 4. German Firms' Strategies for Adjusting to the Gas Crisis, 2022:Q3 and 2022:Q4



Source: NL Analytics.
Note: Percentages for each strategy were calculated by dividing the number of mentions for a specific strategy by the total number of strategy mentions (157) during that period.

where technically feasible, preparations to substitute natural gas by alternative feedstocks are ongoing" (BASF 2022a, 5). Furthermore, the management team acknowledged their capability to decrease gas usage by up to 50 percent without ceasing production (BASF 2022b).

CONCLUSION Policymakers are frequently tasked with addressing the implications of sudden economic shocks. The Russian gas shutoff serves as a quintessential example of such a shock.

In this comment, I have posited that a systematic analysis of earnings calls offers a powerful lens to understand and quantify the impending and immediate impact of such shocks in near real time and before conventional data sources are available. Doing so can provide policymakers with timely data pivotal for shaping policy decisions.

Examining earnings calls held by German and European firms in 2022 fundamentally confirmed the authors' conclusions. We found that German industry was exceptionally dependent on Russian gas. Yet, despite this dependence, the Russian gas shutoff represented a surmountable challenge for German firms—on par with concerns about supply chains and financing constraints but less concerning than, for example, the historically high levels of inflation that prevailed at the time. The gas shock was transitory and highly localized, with its effects predominantly felt within the utilities and basic materials sectors, with no evidence of cascading failures in other sectors. When navigating this episode, the predominant strategies employed by German firms revolved around curtailing their consumption of gas, substituting other sources of fuel, and switching to alternative gas suppliers.

In sum, the insights from my text-centric evaluation align seamlessly with the authors' conclusions, underscoring the validity of their results.

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GENERAL DISCUSSION David Romer said that concrete examples of substitution, such as BASF's shift from domestically produced ammonia to imports from its American plants, are helpful in showing how the paper's main findings manifested themselves in practice. Romer also suggested that the authors avoid using the phrase "decline in demand" to refer to a fall in the quantity demanded. He commented that authors don't currently seem to answer the question of whether the reduction in household gas consumption corresponded to a movement along or a shift of the demand curve. On the one hand, when faced with higher prices, consumers may reduce their consumption or invest in more energy-efficient products—a movement along the demand curve. On the other hand, along the lines of James Hamilton's discussant remarks, if consumers were aware of a possible national crisis and reduced their gas consumption in response, that would constitute a shift of the demand curve.

Caroline Hoxby noted that there were large reductions in household gas consumption, despite gas prices rising only marginally. Hoxby argued that households typically have fewer substitution alternatives relative to firms, and she inquired about the forms of substitution that households might have engaged in, such as adjusting thermostats or investing in warmer clothing.

Claudia Sahm highlighted that the reduction in household gas consumption mirrored the reduction in gas demand by firms. She pointed out that businesses faced the market price for gas, whereas households benefited from incentives to reduce consumption and price caps on natural gas use (Gaspreisbremse). Sahm concluded that firms and households have different substitution possibilities and was intrigued by their almost equivalent reduction in gas demand. On a prior visit to Germany, she observed the government advertisements urging reduced gas use, which she believed supported Hamilton's assessment that a portion of the household consumption drop can be attributed to an emotional response to the Russian invasion of Ukraine and a desire to assist in national efforts.

Moritz Schularick responded that households adopted measures to reduce the quantity of gas demanded in response to higher prices, such as lowering their thermostats, refraining from heating unused rooms, and sealing their doors to prevent cold drafts. However, households also acted to make substitutions for their gas consumption, such as purchasing pellet ovens. Schularick noted that, in most cases, households respond to price changes, but the exact dynamics are complex because retail prices are reset annually and many gas providers operate under longer-duration contracts. Many gas providers failed because they were obligated to provide gas at a low price stipulated by the contracts. The German government intervened to reset some of these contracts. Schularick agreed with Sahm's comment that households likely took efforts to restrict their gas usage for the sake of national security.

Angelos Theodorakopoulos pondered the evidence that German firms replaced significant amount of Russian gas with imports from elsewhere. If such third countries are also highly reliant on Russian gas, the apparent decoupling between overall industrial production and gas-intensive production may actually be trade diversion. He also commented that the aggregate production function modeled in the paper assumes a large cost share for material inputs, which, when produced domestically, are reliant on the Russian gas products. Theodorakopoulos argued that true decoupling does not occur if these material inputs are outsourced from countries that are also highly exposed to Russian gas and oil. Decoupling is persistent, he stated, as opposed to firms and households reducing consumption, relying on stockpiles, and subsequently reverting to their previous behavior.

Georg Zachmann commented that the authors had conducted an analysis that modeled the European gas system as an input-output matrix, allowing them to identify how reduced gas demand in neighboring countries contributed to German supplies. A drop in the Dutch gas demand accounted for 4 percent of German gas supply in the past year, with Belgium contributing 1 percent and France 0.5 percent. Zachmann concluded that the reduced demand in adjacent countries had a substantial impact on German gas supply. He also highlighted that the resilience of the European internal market following the cutoff from Russian gas played a substantial role in Germany's economic adaptability. The country would have suffered greatly on its own, he hypothesized.

Elaine Buckberg noted that the large reduction in gas demand from both producers and households could have potential climate implications. She posited that some of the observed industrial compression was likely due to geographical shifts in production. However, compression not attributable to the relocation of production to lower-cost countries could be of interest from a climate standpoint, she argued. Buckberg wondered whether declines in gas usage could become permanent.

Benjamin Moll responded that the German gas cutoff could potentially be used as a natural experiment to estimate elasticities and examine links in the supply chain. He lamented the limited availability of data but explained that the German statistical agency would be releasing information on gas usage at the sector level later in the year. He advocated for more climate research using data from the gas crisis.

In response to Hamilton's discussant remarks, Schularick agreed that the reactions of firms and households to the German gas cutoff were dependent on effective price signals. He emphasized that agents respond to incentives, linking this idea to the broader discussions on climate change and substitution. The authors investigated the distributional consequences of the gas cutoff and found no evidence that its impacts were regressive. Zachmann emphasized that data from the German gas crisis would be useful in predicting the response of household demand to various shocks and the ability of certain sectors to adapt. Elasticities estimated using these data, he added, could be useful in determining the economic consequences of decarbonization.

Alan Blinder inquired about the significance of liquified natural gas (LNG) and remarked that while the construction of terminals and the processing of natural gas are considered time-consuming, LNG import capacity was critical in the wake of the gas cutoff.

Randall Kroszner noted that substitution could be applied to climate change issues. In response to Tarek Hassan's discussant remarks, Kroszner remarked that analyzing earnings calls to identify differences between what companies announce publicly and what they communicate to investors could inform policy. He also contended that public policy could ease the frictions associated with substitution. Kroszner noted that in Germany, for example, regulators expedited the installment of new LNG terminals, a process that would usually require many layers of approval. In May 2022, the German government approved the terminals, and they were operational in December of the same year, Kroszner explained. He concluded that substitution could take place more easily with adaptive regulation.

Schularick explained that the German LNG terminals were constructed quickly as a policy response to the cutoff from Russian gas. However, a large portion of the LNG imported to Germany came through existing ports and via the Netherlands. He remarked that the floating LNG ports built in the wake of the cutoff, although currently operational, were small and made minimal contributions to the adaptability of German economy. Zachmann agreed, noting that the German LNG terminals became operational in early 2023, and thus they did not play a decisive role in Germany's response to the limitations on Russian gas imports. Currently, the LNG terminals mitigate supply constraints. He credited the moderate economic impacts of the cutoff to demand reductions in neighboring countries and their willingness to supplement limited German supply.

Rebecca Freeman commented that the moderate reductions in output following Germany's cutoff from Russian gas might be a unique outcome, pointing to the particular adaptability of the German gas supply chain, which was able to transition to alternative gas suppliers relatively easily. Freeman pondered whether sectors with more complex or vulnerable supply networks would respond similarly.

Benjamin Golub emphasized that government coordination amid supply chain disruptions is critical to facilitating substitution. Golub also noted that some supply shocks result in smooth adjustments, while others generate an abrupt, discontinuous response. There are examples of both outcomes in complex systems, Golub explained.

Benjamin Harris brought up the supply shocks to semiconductor production, which had an impact on the manufacturing of electronics and automobiles and led to inflation. He pondered why the supply shock to German gas, precipitated by limited Russian imports, generated only marginal effects on production, while the supply shock to semiconductors had more substantial economic consequences. Harris suggested an analysis of the recent supply shocks and their varying impacts on economic activity.

Yongseok Shin commented on the paper's potential climate change implications. A possible unintended takeaway, Shin noted, is that substitutability will allow the economy to adjust easily in the face of climate disasters. He added that with ample planning time, it is possible to determine the most effective ways to substitute.

George Akerlof turned the attention to what he termed an opposite shock—one to the global food supply. Wealthy countries may only face moderate economic effects, while the resultant price increases in poor countries would mean that the population cannot afford food, Akerlof explained. He added that in low-income countries, food will be exported to rich nations, rather than feeding the domestic population. Akerlof noted that such dynamics could be precipitated by global warming, which could produce such shocks to the food supply.

Angus Deaton emphasized that the predictions about German production by economists based on theories of substitutability had proved more accurate than industry analyses. He noted that it is tempting to treat such successes as demonstrations of the superiority of economic tools, but economists need to avoid professional hubris and remember those many occasions on which they were very wrong.

In response to Hassan's discussion, Jason Furman offered an anecdote: in a meeting regarding the 2014 Crimean crisis, the CEO of one of the top five largest oil companies in the world told Furman that the American sanctions on Russia would destroy the company and American jobs. A week later during an earnings call, the CEO assured investors that the sanctions would have no effect on the company—a testament to Hassan's discussion, Furman added.

Furman further commented that, except for short-run demand policy, rigorous modeling of economic phenomena that are commonly discussed in the public domain often reveals minimal impacts: for example, macroeconomic analysis of subjects such as the trade war with China, new trade agreements, infrastructure plans, childcare, and tax reforms, show changes that are mere basis points of annual growth rates. Furman questioned whether the real-world impacts are genuinely as small as these models predict, or if models are instead missing important components, meaning the actual economic implications of policy and macro phenomena are much larger than estimated.

Schularick mentioned his interest in conducting additional analysis using data from earnings calls to identify systematic differences between companies' public announcements and their communications to investors. He recalled that firms from an array of industries voiced concerns over the economic ramifications of restrictions on Russian gas. Schularick noted the automobile industry in particular, which expressed concern about the cutoff publicly but scarcely addressed it during earnings calls.

Justin Wolfers noted the complexity of constant elasticity of substitution models. He proposed an exercise that ranks sectors by energy intensity and simulates a shutdown of the most energy-intensive industries until the quantity of gas demanded declines by 20 percent. Wolfers argued that this type of simulation can be used to gauge the effects of an energy supply shock on the German economy and may be a more effective way of communicating findings.

Zachmann explained that by focusing solely on the most energy-intensive sectors, one could easily observe a 20 percent decline in demand. The most affected sectors are capital- and energy-intensive and have low employment and value-added. Zachmann pondered potential strategies for these industries, such as allowing market forces to determine their fate or providing subsidies in the hope that energy will be cheaper in the future. Şebnem Kalemli-Özcan brought up one of her own papers, which calibrates an open economy adaptation of the Baqaee-Farhi model that considers both trade and domestic elasticities.[1] She emphasized the importance of differentiating short- and long-run elasticities and explained that the most significant source of variation in predicting the price impact of a supply shock is the shift in the elasticity of substitution above and below one. Using domestic and international elasticities calculated by Boehm, Pandalai-Nayar, and Levchenko,[2] the model highlights the differing price impacts of a supply shock in the near and far term as elasticities shift to imply substitutes rather than complements in production, Kalemli-Özcan explained. She argued that this type of model can accurately explain price and output dynamics.

In response to Hamilton's discussion on the business cycle effects of the German gas cutoff, Schularick offered several comments. He explained that the paper did not include a full analysis of the business cycle effects due to time constraints. Schularick elaborated on the findings of the Baqaee-Farhi model presented in the paper. Specifically, the model predicted a GDP decline of about 1 percent but acknowledged an upper bound of about 3 percent, accounting for the business cycle amplification effects. Some of the authors of the original "what if?" paper[3] produced a subsequent publication with a more comprehensive analysis of the business cycle implications. They found similar effects when allowing for business cycle amplification.

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